

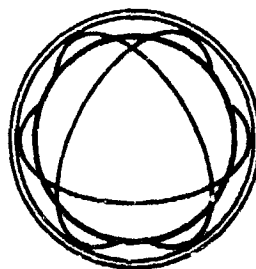
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FINAL DESIGN & TEST REPORT

OTTA

OXYGEN THERMAL TEST ARTICLE



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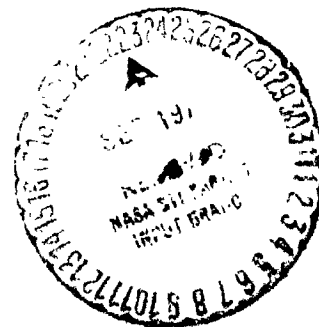
NAS 9-10348

FINAL DESIGN & TEST REPORT

ER-15961

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OXYGEN THERMAL TEST ARTICLE (OTTA)

by

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Prepared for

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Contract NAS 9-10348

NASA MANNED SPACECRAFT CENTER

Houston, Texas

Robert K. Allgeier, Project Monitor

FINAL REPORT ER 15961



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FINAL DESIGN & TEST REPORT
PROPULSION CRYOGENIC TANKAGE FOR EXTENDED MISSION CAPABILITY
OXYGEN THERMAL TEST ARTICLE (OTTA)

1.0 INTRODUCTION

This report is prepared by Beech Aircraft Corporation, Boulder Division, Boulder, Colorado, in compliance with NASA Contract NAS9-10348 for a nominal 225-cubic-foot capacity cryogenic storage tank known as the Oxygen Thermal Test Article (OTTA).

The cryogenic tank produced under Contract NAS9-10348 is capable of storing liquid hydrogen, nitrogen, oxygen, methane, or helium for an extended period of time with minimal losses. At the time of the original contract, this particular tank was designed to meet the requirements of the shuttle oxygen system. Since September 1971, when a cryogenic orbital maneuvering system (OMS) was eliminated from the baseline design, it has become primarily an advanced thermal technology test bed.

This final design and test report includes: a full description of the tank and control module, assembly drawings, and details of major sub-assemblies, a listing of the specific requirements controlling development of the system, thermal concept consideration, thermal analysis methods, structural analysis, a schedule of the period of performance, and a record of the test results.

Performance of the OTTA insulation system was outstanding. The results exceeded the proposed thermal effectiveness by as much as 2.5 times. Testing, originally planned for liquid nitrogen only, was expanded to include liquid hydrogen and liquid helium. Results of the additional testing were equally satisfying with values of thermal effectiveness better than the original estimates.

The OTTA thermal protection system has proven, through extensive testing, that the capability to design and produce very effective and sophisticated insulation systems for cryogenic vessels is indeed practical. Utilizing Beech computer programs, effectiveness of future cryogen insulation systems can be predicted and designed to exacting specifications.



2.0 SUMMARY OF THE PROPULSION TANK PROJECT

2.1 Objective

The objective of the program was to design and fabricate a prototype cryogenic tank for long-term storage of propellants. A secondary objective was to provide a "test-bed" design that would allow an efficient way to replace the insulation materials. The design was to have planned for an efficient thermal protection system that would perform in space in any orientation or gravitational field. The weight of the thermal system was to approach a flight-weight installation.

2.2 General Description of the Completed OTTA

The tank developed as a result of this contract is a double walled spherically shaped vessel that contains a nominal volume of 225 cubic feet in the inner tank. The cryogenic pressure vessel is supported by a lightweight suspension system of glass/epoxy filament wound circular rings. The insulation system radiation barrier is multilayer metallized mylar with silk net spacers. To obtain maximum efficiency two aluminum shields are strategically placed in the vacuum annulus and cooled by the discharging boil-off vapor. The pressure vessel and insulation system are suspended inside of a circular girth ring which is mounted in trunnion bearings on a mobile handling fixture. The polar hemispheres are closed with solid aluminum shells forming a vacuum tight jacket around the cryogen container. A complete description of the major subassemblies is included in the mechanical design section of this report (Section 7.0). Arrangement drawings and major subassembly drawings are included in the appendix.

2.3 Specific Design Approach

To accomplish the objective of the program, that is, long-term storage of cryogens, it was necessary to give particular attention to the thermal protection and suspension systems. The desire for a somewhat lightweight construction dictated the use of low density metal for the pressure vessel and supporting structure. Pressurized components of the dewar system that contain the cryogens were designed in a conventional manner and specialized tooling was fabricated to accommodate the particular size. The thermal protection system which includes the pressure vessel suspension system required a unique and detailed investigation. A design specification required that vapor only would be discharged from the vapor-cooled shield regardless of the orientation or gravitational field imposed. The OTTA design accommodates this requirement and allows for the possibility of the vapor-cooled shield opening inside the pressure vessel being submerged in fluid as well as open to the vapor space. The well-known value of a vapor-cooled shield was investigated to determine the potential benefit of applying the same theory in a new area. If the additional refrigeration available from the cryogen in a liquid form could be utilized to intercept "minor losses" before they reach the storage vessel, a dual benefit would



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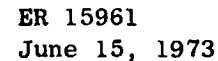
be realized in accommodating liquid, as well as vapor flow, and at the same time reducing the total heat influx. An IBM 360 Computer Program using a nodal network was employed to analyze the insulation system with the subsequent determination that most of the heat finally arriving at the pressure vessel could be absorbed at the proper temperature if an area collection system was provided. A shield of high conductivity material designed as a "boiler" was developed for approximately 80% of the pressure vessel surface. With suitable radiation shielding between the "boiler" and pressure vessel, the optimum temperature was attained at the boiler. In operation, the boiler and vapor-cooled shield (VCS) flow systems provide efficient cryogen protection with only minor temperature variations at the discharge point for any orientation of the vessel axes.

The suspension system for the cryogen container was conceived as a regular pattern of interacting uniform bands that would completely encompass the spherical vessel and provide support in all directions. The bands are made of low conductivity material. The concept of the support system presented only one real problem to the designer. That is, how to weave the rings into a symmetrical support system after producing them as individual elements? The elements were envisioned as circular rings with tangential extensions providing the primary support contact with the ambient temperature outer shell. The number of rings would determine the number of penetrations through the insulation. Since it is desirable in an optimized support system to have as few penetrations as possible, the desired loading was analytically applied to the spherical pressure vessel to determine the amount of support required in each of the three axes and subsequently determine the minimum number of rings required to react the loading. Three support rings were chosen as the minimum for satisfactory load reaction. The weaving of the rings was accomplished by minor local deviation in the circumference of the outer two rings.

Manufacturing processes were investigated to determine the optimum method for producing interwoven rings of low conductivity material. Filament winding of epoxy impregnated glass was selected to produce the best ring configuration. Filament wound rings provided a uniform material without the necessity for joints. However, the rings could not be interwoven using this method for construction. By varying the ring diameters and adjusting for cross-over dimensions the three rings could be assembled to produce the interwoven effect. Orientation and relative angularity of the rings was selected in relation to the variation in loading direction (7 g axial, 3 g side). Attachment Points (6) were made to fall in a single plane at the equator to accommodate support for the completed assembly.

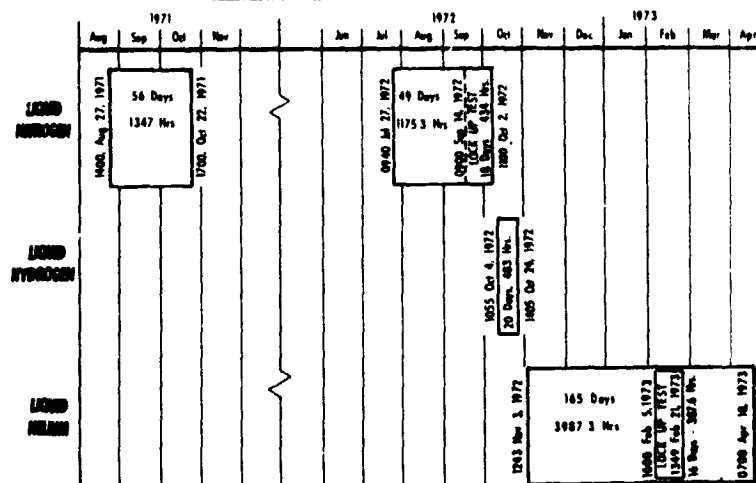
2.4 Specification Control

In order to provide the maximum freedom in design and fabrication technology, control documentation was minimized. The development of the long-term storage dewar was experimental in nature. However, Beech Aircraft Corporation elected to impose certain essential material and process specification controls in



2.5 Test Examination

OTTA
CRYOGEN TEST RECORD



In 1972, after repair of the leak, performance was improved to 0.042 Btu/hr-ft² for liquid nitrogen, which to our knowledge represents the best performance that any dewar of comparable size has ever displayed.

Liquid helium testing over a period of 165 days allowed thorough examination of the unit under the most critical circumstances. Thermal performance was again excellent at 1.22 Btu/hr. Observation was made of the effects of no-loss storage and storage without the use of the vapor cooled shield. Finally the extended period of storage demonstrated that liquid helium could be successfully stored for as long as six months if careful precautions were exercised.

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3.0 SCHEDULE OF EVENTS

The schedule of events and significant milestones during production of the oxygen thermal test article are shown in Figure 1.

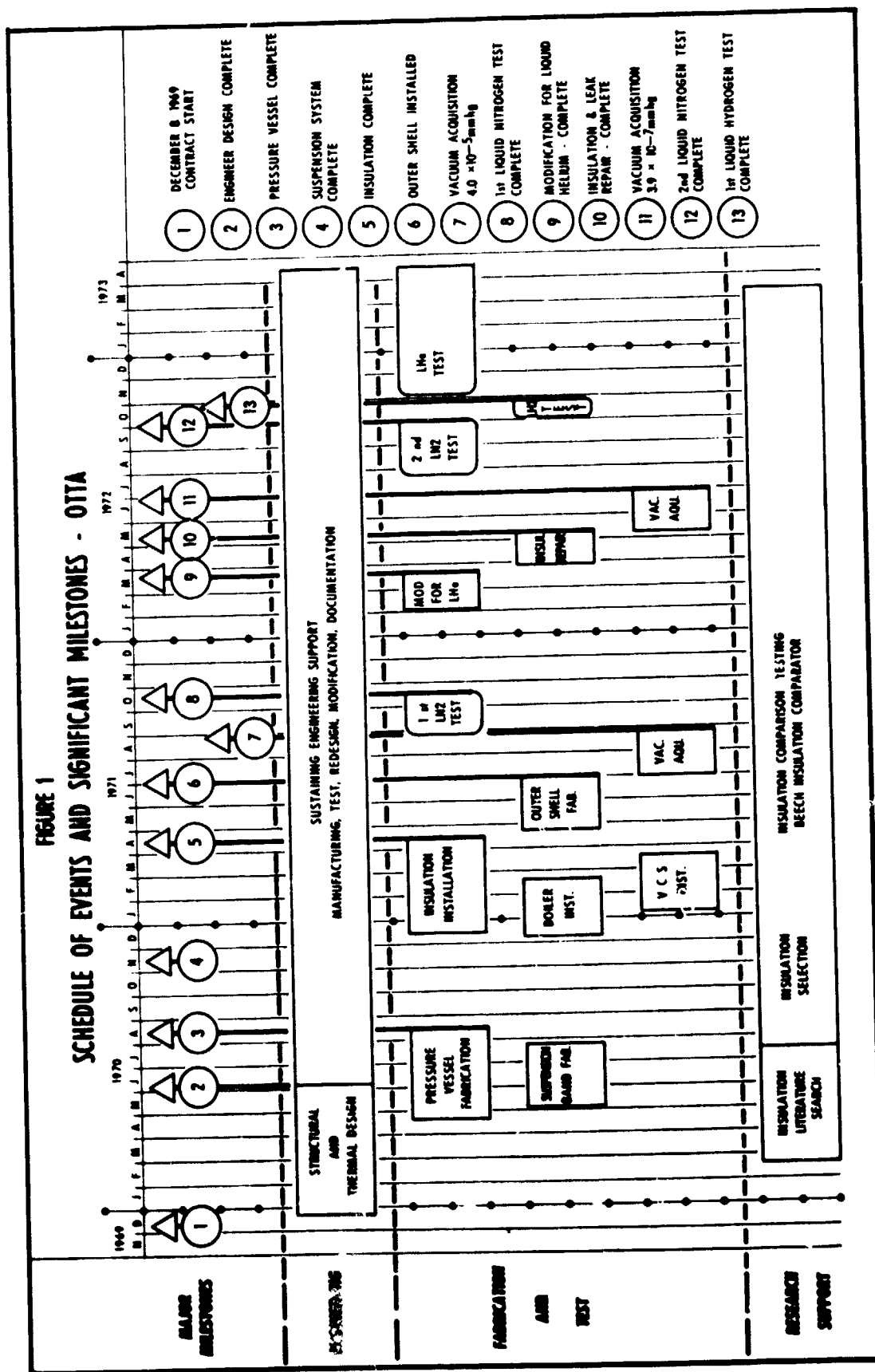
The term of the original contract was extended from 12 months to 24 months due to concept changes, difficulty in obtaining insulation material and a failure of an experimental, non-metallic, honeycomb outer shell. The original contract work statement did not require a rigid outer shell since the unit was to be tested inside of a large vacuum chamber at the NASA test facility in Houston. A supplemental contract was issued to provide the hard outer shell when determination was made that significant advantage would be offered to the program by having a self-contained vacuum. The outer shell as proposed was to be flight weight fiberglass honeycomb construction. Following failure of the experimental honeycomb shell during an evacuation test a rigid aluminum outer shell was designed and fabricated.

A fiberglass honeycomb scale model outer shell was subsequently designed constructed and tested to satisfactorily prove the technical feasibility of producing this type of lightweight shell.

An additional contract to include testing with hydrogen and helium extended the project schedule by five months.

When the first nitrogen test was performed, a very minute leak was discovered in the vapor-cooled shield system. The leak was not large enough to cause the test to be discontinued. However, when the unit was modified for helium service a small additional time was used to repair the vapor-cooled shield system.

FIGURE 1
SCHEDULE OF EVENTS AND SIGNIFICANT MILESTONES - OTTA



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4.0 SPECIFICATIONS

4.1 Physical Requirements

Contained Volume:	225 ft ³ maximum
Stored Fluid:	LH ₂ , LOX, LN ₂ , CH ₄ , or LHe
Pressure Vessel Safety Factor:	2.0 based on tensile yield
Outer Envelope Restriction:	Movement through a 10-foot diameter door
Acceleration Loading:	7 g axial, 3 g side
Pressurization Type:	External to system

4.2 Operational Parameters

Maximum Pressure:	150 psia
Flow Rate:	10 lb/sec LOX minimum @ 100 psia
Environment:	Nominal 70°F ambient vacuum -65°F to +140°F -- no degradation Extended periods @ 1 atmosphere 100% relative humidity

4.3 Performance

Minimum Mission:	180 days
Ground Hold:	50 hours
Heat Leak/Stored Mass:	Minimum
Insulation Weight/Stored Mass:	Minimum

4.4 Instrumentation

Stored Fluid:	Temperature Pressure
Insulation:	Temperature Pressure (vacuum)



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5.0 WEIGHT

The system is designed as a prototype in which thermal performance was and weight was not a prime consideration. The design approach considered practical application of common fabrication technology and none of the elements of the system were specifically weight optimized. A tabular presentation of prototype weights and estimated flight weight design of comparable elements is shown below:

<u>Useable Stored Media</u>	<u>Weight--Pounds</u>
Liquid Hydrogen	981
Liquid Oxygen	15,810
Liquid Nitrogen	11,188
Liquid Methane	5,863
Liquid Helium	1,732

<u>System Elements</u>	<u>Prototype</u>	<u>Flight Estimate</u>
Handling Fixture	1,415	N/A
Pressure Vessel	1,112	400
Fill and Vent Lines	71	49
Suspension System	318	73
Multilayer Insulation)		
Boiler Shield) System	131	110
Vapor Cool Shield)		
Girth Ring	461	225
Outer Shell	767	175
Instrumentation		
Pressure	5	2
Temperature	1	1
Vac-Ion	41	17
Fluid Control Module	68	40
Miscellaneous Hardware	27	10
TOTAL	4,417	1,102



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6.0 DOCUMENTATION

6.1 Government Documents

NASA CR-74545	Material Data Handbook Aluminum Alloy 2219
NASA CR-912	Shell Analysis Manual
NAS9-10348	Exhibit A, Work Statement
NASA CR-72114 (NAS3-6287)	Cryogenic Resins for Glass-Filament Wound Composites
AFML TDR 64-280 Volume II	Cryogenic Materials Data Handbook
MIL-W-8604	Specification for ARC Welding Aluminum
MIL I-6865	Radiographic Inspection Method

6.2 Boeing Aircraft Corporation Documents

DD 15961	Cryogenic Tankage for Extended Mission Capability
BS 13779	Cleaning Components for Liquid Oxygen and Hydrogen
ER 15423	O ₂ Thermal Test Article Structural Analysis Report
BP 15438	Design Verification Test Procedure, O ₂ Thermal Test Article
BP 15534	Liquid Nitrogen Design Verification Test Procedure, O ₂ Thermal Test Article
BP 15551	Liquid Hydrogen and Liquid Helium Design Verification Test Procedure, O ₂ Thermal Test Article
ER 15440	OTTA Honeycomb Outer Shell Failure Report
ER 15441	OTTA Outer Shell Report
ER 15439	New Technology Report of a Filament Wound Suspension System for a Cryogenic Tank
ER 15507	Failure Analysis Vapor-Cooled Shield Adapter Joint - OTTA



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Cable and Pad Thermal Support System Computer
Program (THERM)

6.3 Other Documents

Unpublished Study, Bifurcation Phenomena in Spherical Shells Under Concentrated and Ring Loads, David Bushnell, Lockheed Palo Alto Research Laboratory.



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7.0 MECHANICAL DESIGN

7.1 Physical Description (Drawing 460966A)

The cryogen container is spherical in shape and is suspended inside of a spherical vacuum jacket by three (3) glass filament-wound bands. The space between the vessel and jacket contains a multilayer insulation system enhanced by a "boiler shield" and vapor-cooled shield (VCS). The complete dewar assembly is supported at the equatorial "girth ring" in trunnion bearings mounted on a mobile handling fixture. Within the fixture, the dewar assembly may be rotated through 360 degrees to simulate various operational attitudes which might be encountered in space.

Penetrations to the inner vessel and evacuated annular space all pass through the girth ring structure. The penetrations consist of a liquid line, a vapor vent line, a vapor-cooled shield vent line, ion-type vacuum pump port, evacuation port, vacuum relief port, gage port, and two electrical instrumentation feed-throughs. Liquid, vapor vent, and vapor-cooled shield lines penetrate the inner vessel at the same "pole" location. An extension to the vapor vent and vapor-cooled shield lines extends across the inside diameter of the tank from the penetration location to the opposite "pole" of the vessel.

A space envelope of 132.0 inches in diameter by 126.0 inches long completely encloses the dewar assembly, handling fixture, and attached instruments. Flexible external cryogen lines (not furnished per contract) connect through "AN" standard fittings to a separate control module (drawing 660995). The control module is not attached to the dewar or support structure since it is planned to be a semi-remote operation unit. The control module structure is made of aluminum angle enclosed with aluminum sheets to form a box with envelope dimensions of 13 x 17 x 25 inches. Valves controlling the liquid and vapor phase flow and a separate pressure gage for each system are mounted on one aluminum panel marked to indicate the flow paths. Connecting tubes and fittings within the control module are stainless steel.

Aluminum alloys were used wherever possible in the construction of the dewar elements. For heat transfer reduction in the fill and vent tubing, the section passing through the evacuated space is made of stainless steel and joined to the aluminum end pieces through aluminum/stainless steel bimetal tubing sections. Instruments, valves, vacuum ion pump and vacuum ion gage are commercially available equipment.

A complete organization of drawings is shown in Table 2 which is arranged in the manner in which the drawings apply in the fabrication process. The following drawings are included in this report (Appendix) for overall description and replaceable parts identification:

460966A	General Arrangement
460992	Fluid Flow Schematic
660995	Module - Control, External



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460947	Gage Assembly - Ion
660969	Support Installation
660943	Temperature Sensor Installation

7.2 Thermal Design and Concepts

The primary thermal design goal in the development of this cryogenic tank was storage of two-phase cryogenic fluid for extended periods of time (180 days or longer). The secondary goal was to obtain this minimum boil-off rate with a minimum insulation system weight.

The performance characteristics were designed using an unusual tension band support system. Multilayer insulation consisting of silver-coated 1/4 MIL mylar with silk net spacers, and a vapor cooling system which takes advantage of the refrigeration available in the boil-off gas. The thermal protection system consists of:

- (1) Pressure Vessel (PV) Support System
- (2) Support Pads
- (3) Outer Shell (OS)
- (4) Multilayer Insulation (MLI) between Outer Shell and Vapor-Cooled Shield
- (5) Vapor-Cooled Shield (VCS)
- (6) Multilayer Insulation between Vapor-Cooled Shield and Boiler Shield
- (7) Boiler Shield (BS)
- (8) Multilayer Insulation between Boiler Shield and Pressure Vessel
- (9) Vapor Cooling on Support Bands near the Girth Ring

The OTTA is capable of storing oxygen, nitrogen, hydrogen, methane, and helium.

7.2.1 Support System

The tension band support system minimizes the heat leak into the pressure vessel in several ways. The primary advantage of this support system is that the bands are made of filament-wound glass which provides an extremely high ratio of strength-to-thermal conductivity. The allowable design stress of these bands is 77,600 psi and the mean thermal conductivity is 0.15 Btu/ft-hr-°R. The thermal conductivity of the bands has a temperature dependence which resembles that of a typical linear radiation conductance. Consequently there is a tendency for the temperatures of the passive radiation shields to match the temperatures of the support bands, thus providing a possible reduction in edge effects at the penetrations.

7.2.2 Support Pads

One-inch-thick pressed fiberglass pads were placed between the support bands and the pressure vessel at the locations where contact is first made. These pads provide a reduction in the heat leak through the support system in two ways. First, the thermal conductivity of the pads is extremely low (0.003 Btu/ft-hr-°R). Secondly, the pads elevate the support bands above the pressure vessel and allow a greater band length from the girth ring to the pressure vessel.



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7.2.3 Outer Shell

The hard outer shell (portable vacuum jacket) makes it possible to maintain the entire insulation system in a 10^{-6} torr vacuum. Heat transfer by convection and gaseous conduction are essentially eliminated.

7.2.4 Multilayer Insulation (MLI)

The passive radiation shields consist of 1/4 mil mylar sheets coated with silver on both sides. Adjacent shields are separated by two sheets of 0.003-inch thick silk net. Company-funded testing and data available in the literature indicate that of those MLI materials which are available, this combination provides the best insulation per pound. Company-funded testing also showed two layers of silk net to be a more beneficial spacer than one or three layers. There are three radiation barriers between the pressure vessel and the boiler shield, 15 between the boiler shield and the vapor-cooled shield, and 28 between the vapor-cooled shield and the outer shell.

Each radiation shield is sandwiched and sewn between two sheets of silk net, and the shields themselves do not contact the penetrations. There is limited contact between the net and the penetrations. The dominant mode of heat exchange between the radiation shields and the penetrations is consequently radiation. Edge effects at the penetrations are reduced by wrappings around the penetrations which consist of three layers of silver-coated mylar separated with silk net.

It is extremely difficult to fabricate and lay up the radiation barriers so that no gaps exist at the penetrations. The method used to minimize the effect of the "gaps" is to add a "patch" of approximately one-foot square silver-coated mylar fitted snugly around the penetration. These "patches" are placed at every fifth layer of insulation.

7.2.5 Vapor Cooling

In order to maintain constant storage pressure, fluid must be expelled from the pressure vessel to accommodate the heat leak. During zero-g operation, this "boiloff" fluid may be vapor or liquid, or most likely a combination of both. The fluid which is expelled from the pressure vessel due to the heat leak passes through approximately 350 feet of tubing before it exits the tank. This tubing is first routed over the boiler shield, then over the vapor-cooled shield, and then fastened to an aluminum shorting strap at each point of attachment of the support straps to the girth ring. The tubing is attached to the boiler shield and vapor-cooled shield by clips which are 6 inches apart. The vapor-cooled shield covers the entire surface area of the tank while the boiler shield covers 82% of the surface area.

As the fluid flows out through the vapor-cooling tube, it absorbs heat which is entering the tank by both radiation and conduction. The vapor



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will exit the tank at some temperature between -10°F and $+70^{\circ}\text{F}$. The exit temperature depends on the storage pressure, the fluid being stored, and whether vapor or liquid is being expelled from the pressure vessel. Vapor cooling provides a heat leak reduction of about 30% for oxygen, nitrogen, and methane and about 80% for hydrogen and helium.

7.2.6 Boiler Shield (BS)

The primary function of the boiler shield is to condition the "boil-off" fluid; i.e. to vaporize any liquid which is expelled from the pressure vessel. During vapor expulsion operation, the boiler shield acts as a second vapor-cooled shield and provides additional reduction in heat leak.

In order to optimize the performance of the boiler shield during both vapor and liquid expulsion,

- (1) all heat leaks were channeled into the boiler shield instead of the pressure vessel, and
- (2) the boiler shield was insulated from the pressure vessel.

This first requirement is necessary so that during liquid expulsion from the pressure vessel, the boiler shield will intercept enough of the heat leak to vaporize the expelled liquid. All plumbing and support bands are thermally shorted to the boiler shield at locations near the pressure vessel. The second condition is desirable so that during vapor expulsion operation, the boiler shield will perform more effectively as a second vapor-cooled shield. In order to insulate the boiler shield from the pressure vessel, radiation barriers were placed between the pressure vessel and boiler shield, and the boiler shield supports were designed to offer maximum resistance to heat conduction from the boiler shield into the pressure vessel.

It is not necessary that the boiler shield cover 100% of the tank surface in order to function adequately as a "boil-off" fluid conditioner. Analytic predictions indicate that for pure liquid expulsion with 82% boiler shield area coverage, a small amount of liquid will escape the boiler shield and enter the vapor-cooled shield during storage of oxygen, nitrogen, and methane. Any liquid entering the vapor-cooled shield will be quickly vaporized.

Optimum operation during an extended mission is obtained by allowing part of the heat leak to be absorbed by the stored liquid. This will cause the storage temperature and pressure to rise. The optimum procedure would be to start with a nominal fill pressure of 15 psi, and to allow the stored liquid to absorb enough heat so that the storage pressure rises to the allowable maximum by the end of the storage period.



7.2.7 Thermal Analysis and Results

The thermal analysis required during the development of this cryogenic tank and the predictions of the thermal performance were performed with the Beech Aircraft Thermal Analyzer Program (TAP). Studies to maximize the delivered fluid weight by allowing the heat leak to produce a pressure rise were performed with computer programs PROXY, PRHYD, and PRNIT. All of these computer programs operate on the Beech Aircraft IBM 370 Computer.

TAP utilizes a "lumped parameter" finite-difference method to perform transient or steady-state solutions for a wide variety of thermal problems involving conduction, radiation, convection and/or fluid flow. The "lumped parameter" method consists of representing a physical problem by a network of point masses (nodes) which are connected by conduction, radiation, and/or convection heat transfer paths. TAP utilizes a "block relaxation technique to perform steady-state solutions and uses temperature fluctuation to determine convergence. The energy balance of the entire system was also examined to ensure the validity of each solution. The capability and applicability of the program are enhanced by flexible input techniques and by many "special functions" which can be used to construct thermal models. Thermal models may contain as many as 1000 nodes, 2000 paths, 500 "special functions" and 4000 tabular entries for specifying curve fits.

Programs PROXY, PRHYD, and PRNIT use a simplified thermal model to compute heat leaks and time histories of cryogenic tank storage conditions. These programs apply to subcritical and supercritical storage of oxygen, hydrogen, and nitrogen, respectively. The thermodynamic properties of the stored fluids and the thermodynamic functions needed to determine expulsion rates and pressure rise rates are computed internally.

7.2.7.1 Support Bands

Computer program TAP was used to compute the temperature profiles along the support bands, from the girth ring to the pressure vessel, which would exist if the bands were thermally isolated from the rest of the system. The following values of thermal conductivity were used for the filament-wound glass bands.

T ($^{\circ}$ R)	20	210	310	360	410	460	510	560	610
k (Btu/ft-hr- $^{\circ}$ R)	0.06	0.09	0.12	0.14	0.17	0.22	0.29	0.40	0.54

This temperature profile was used to determine optimum locations for the shorting straps which connect the support bands to the boiler shield and to evaluate the effect of the vapor-cooled shield support members which are attached to the support bands.

In considering the optimum design, a variable attachment point was found to be needed for the shorting straps that reach from the boiler shield to the



suspension bands. In the case of liquid expulsion from the pressure vessel it was found that the boiler shield would be at liquid temperature requiring the shorting straps to be positioned as close as possible to the insulation pads. In the case of vapor expulsion the boiler shield temperature was found to be warmer than the insulation pad which would require the shorting straps to be located some distance away from the insulation pads to preclude heat flow from the boiler shield to the pads. Based on the temperature difference determined from computer analysis the shorting straps were located three inches from the insulating pads.

The undisturbed band temperature at the location of the vapor-cooled shield supports is generally 50 to 100°F lower than the predicted vapor-cooled shield temperatures. The undesirable effect of this condition is that heat will flow from the vapor-cooled shield into the bands. This effect is minimized by using low conductance nylon support pieces with the smallest area-to-length ratio consistent with structural integrity.

7.2.7.2 Boiler and Vapor-Cooled Shield

A typical triangular segment of the boiler shield was analyzed in detail in order to determine how the entire boiler shield and vapor-cooled shield could be represented with reasonable accuracy and simplicity in a thermal model of the complete insulation system. A thermal model for the resulting right spherical triangle, with a base of three feet and a height of seven feet and with the vapor-cooling tube attached along the centerline, was constructed using 400 nodes. Each node receives a radiative heat flux on one side, radiates to a cold sink on the other side, and exchanges heat by conduction with surrounding nodes.

In order to facilitate this analysis, it was assumed that the tube is in perfect contact with the sheet and that there is no difference in temperature between the tube and the vapor. The justification of these assumptions will be explained.

The vapor-cooling tube is made of 0.187 inch OD x 0.028 inch wall aluminum and is attached to the boiler shield and the vapor-cooled shield with clips which are six inches apart. If there is contact between the tube and shields only at the clips, the approximate amount of heat which must be conducted from the shield into the tube at a typical clip location is 0.05 Btu/hr. The temperature difference required to conduct half this heat through a three-inch length of the vapor-cooling tube is 0.5°R. The estimate of this temperature difference is very conservative since (1) the heat must only be distributed along the three-inch section of tube and not conducted all the way through it, and (2) there will generally be some contact between the tube and shield between the clips. The resistances to heat flow between the shield and the vapor-cooling tube are considered small enough to be neglected in the thermal model without affecting the predicted thermal performance of the shields.



For the predicted vapor-cooling flow rates of 0.2 lbm/hr for oxygen and 0.03 lbm/hr for hydrogen, estimated film coefficients for transfer of heat from the tube wall to the vapor are 2.0 and 10.0 Btu/ft²-hr-°R, respectively. The temperature differences required to pass 0.05 Btu/hr from the wall of a 6-inch length of vapor-cooling tube into the vapor are 1.5°R for oxygen and 0.3°R for hydrogen. Neglecting this small temperature difference will have little effect on the overall accuracy of the thermal model.

Computer runs were made with the thermal model of the boiler shield segment for a variety of incident heat fluxes, cold sink temperatures and tube temperatures. Both constant and linearly varying tube temperatures were considered. It would have been a simple matter to connect the tube nodes together with fluid flow paths and thus allow the tube temperatures to be computed as part of the solution. For the purposes of this investigation, it was considered more informative to fix the tube temperatures.

For the expected range of heat fluxes incident upon the boiler shield and vapor-cooled shield the temperatures at the edge of the triangular segment were within 1°R of the tube temperatures. In the cases where the tube temperature was varied from one end to the other, the variation in shield temperature was varied from one end to the other, the variation in temperature in the direction normal to the tube was within 2°R for any given row of nodes. It was concluded that for construction of a thermal model for the entire insulation system, the boiler shield and vapor-cooled shield could be represented with reasonably few nodes. Each of these nodes would represent an isothermal section of shield and attached tube with fluid flowing through it, which are all at one temperature. Heat will flow into and out of each of these nodes due to radiation, conduction, and fluid flow. Conduction paths which represent the boiler shield and vapor-cooled shield supports and the shorting straps to the support bands and plumbing will be connected to some of these nodes.

The specific heat of the cooling vapor is considered to be constant, and its value is determined from the temperature and enthalpy changes of the vapor between the pressure vessel and tank exit. The assumption of constant specific heat has very little effect on the predicted heat leaks, except in the cases of hydrogen at high storage pressures. One solution using temperature-dependent specific heat was performed for hydrogen with a storage pressure of 10 atmospheres. The computed heat leak was 3% smaller than that computed with constant specific heat. Thus, the indication is that the actual tank will perform better than anticipated (which it did). Future improvement in the computer program should include this consideration.

7.2.7.3 Multilayer Insulation (MLI)

The insulation effectiveness of the MLI blankets is represented in the thermal model with a total emittance (ϵ_{eff}). The value of ϵ_{eff} depends on surface emittances, number of layers in the blanket, penetration gaps, edge effects, and boundary temperatures. Evaluation of ϵ_{eff} is the largest



source of inaccuracy in this analysis. Values of ϵ_{eff} must be based upon data available in the literature, upon experimental investigations with the Beech Insulation Comparator, and upon estimates of layup degradation which are obtained from available data and Beech experience.

The values of ϵ_{eff} which were used for this analysis were 0.01, 0.0016, and 0.0016 for the 3-, 15-, and 28-layer blankets, respectively. Some problems were run for a range of ϵ_{eff} in order to assess the amount of error which would result from inaccurate evaluations of ϵ_{eff} .

7.2.7.4 Thermal Model for Entire System

The thermal model and nodal network used to predict the tank performance during constant pressure operation are shown in Figure 2. The nodal energy balance which is performed by computer program TAP is shown in Figure 3 for a typical vapor-cooled shield node.

The vapor-cooled shield is represented with 32 identical nodes, and the boiler shield is represented with 16 identical nodes (i.e. one node for each half of the 8-triangular segments which comprise the boiler shield. While the representation of the vapor-cooled shield with 32-series connected nodes is not rigorous, it is adequate and consistent in this analysis. The specific heat of the vapor is considered a constant which is determined by the difference in temperature and enthalpy between the pressure vessel and tank exit.

Each vapor-cooled shield node exchanges radiation with the outer shell and with the boiler shield node beneath it. Each boiler shield node exchanges radiation with the pressure vessel and with the two vapor-cooled shield nodes above it. Since the boiler shield area coverage is less than 100%, the vapor-cooled shield nodes also exchange radiation with the pressure vessel. Notice that the inlet to the vapor-cooled shield is directly over the exit of the boiler shield and vice versa. The vapor-cooling tube is routed in this manner in an effort to eliminate "hot spots" on the tank.

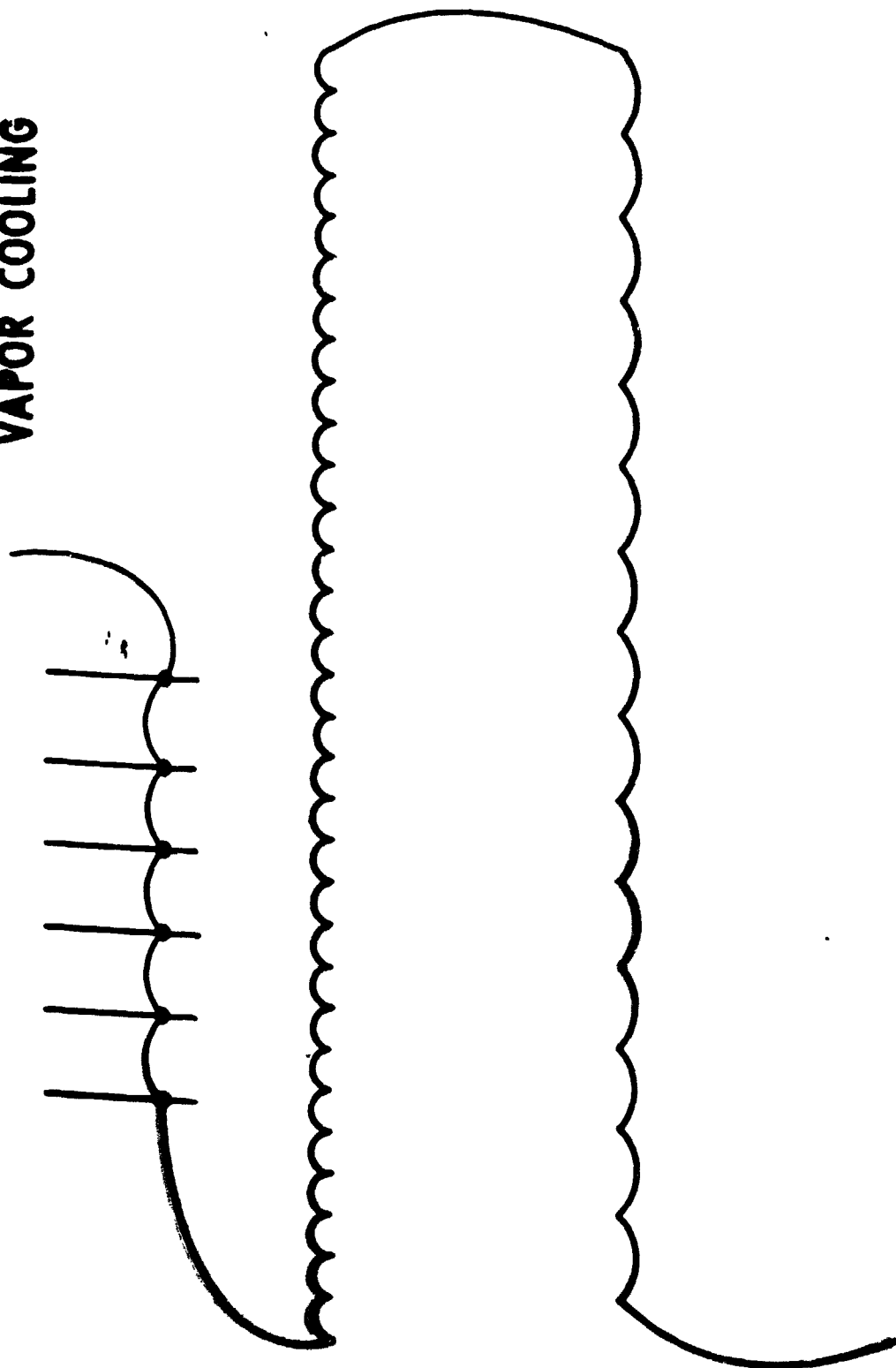
Adjacent vapor-cooled shield nodes are connected with a path which represents conduction through the sheet metal and a path which represents absorption of heat by the vapor as it flows from one node to the next. Adjacent boiler shield nodes are also connected by paths representing vapor flow, but only pairs of nodes, each pair representing one of the triangular segments of the boiler shield, are connected with conduction paths.

Since pairs of support bands are shorted to the boiler shield at a location represented with a single boiler shield node, each pair appears in the thermal model as one band. Each band in the thermal model contains seven temperature-dependent conduction paths.

Notice that the support bands are thermally shorted to the boiler shield at the three-triangular segments nearest the inlet to the boiler shield (excluding the polar segment). This was done so that the temperature of the boiler shield at the locations of the shorting straps would be as low as possible. The fill and vent lines also are thermally shorted to the triangular segment nearest the inlet.

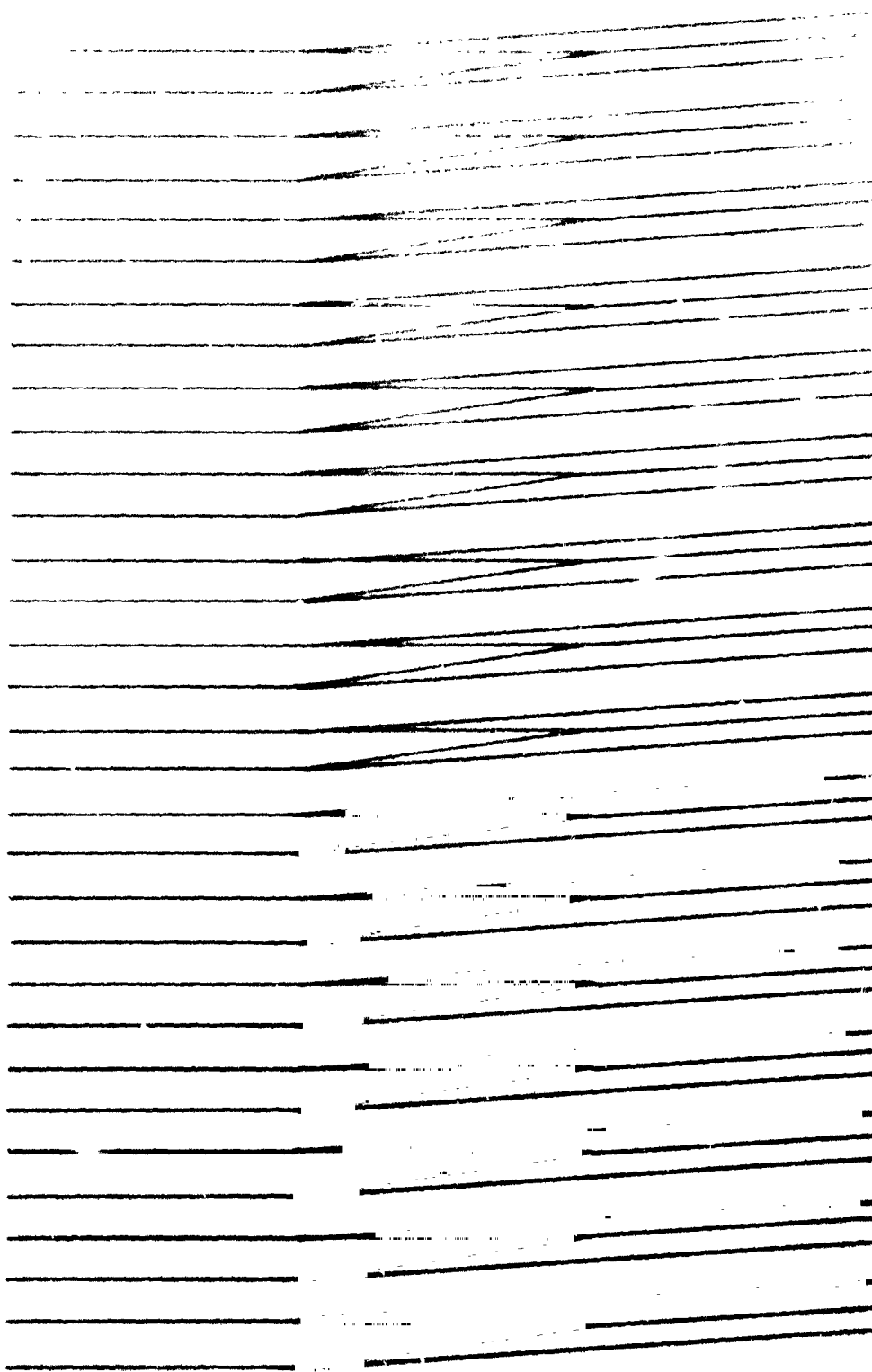
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VAPOR COOLING

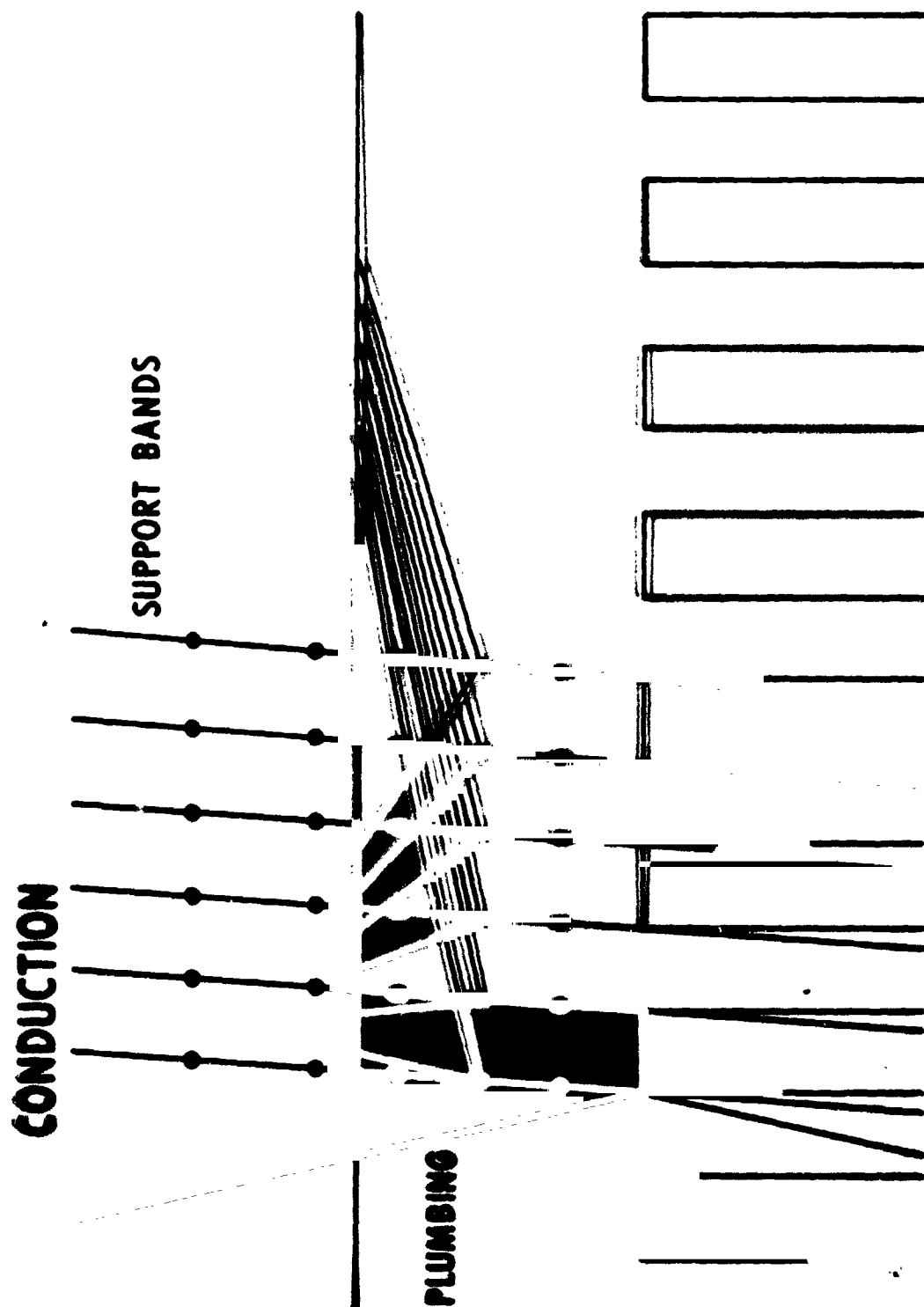


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RADIATION



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THERMAL ANALYZER PROGRAM

THERMAL MODEL FOR O₂ THERMAL TEST ARTICLE

OUTER
SHELL

VCS

BOILER
SHIELD

PRESSURE
VESSEL

- OUTER SHELL AND PRESSURE VESSEL ASSUMED ISOTHERMAL.
- CONDUCTANCE OF SUPPORT BANDS IS TEMPERATURE DEPENDENT.

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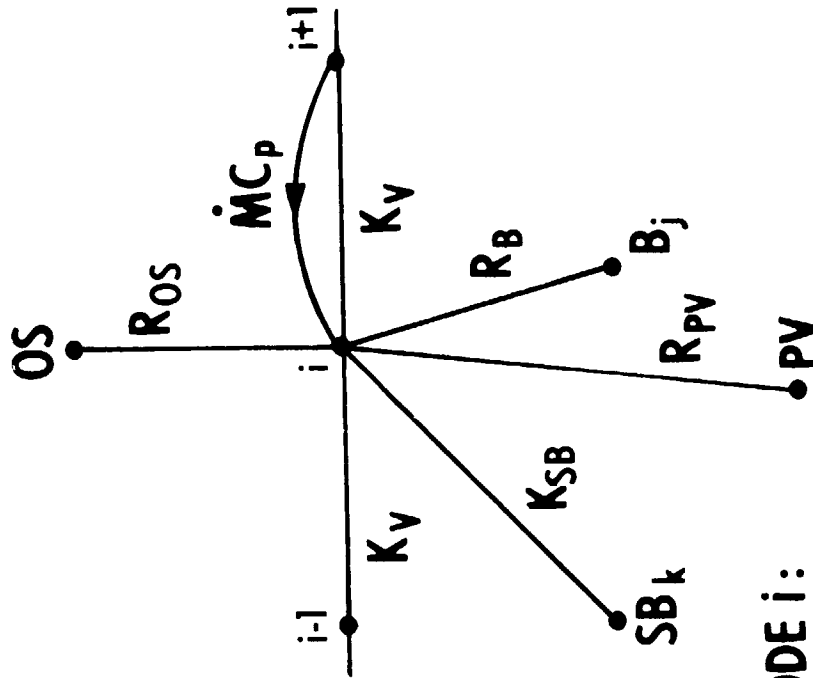
Figure 2



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Figure 3

NODAL ENERGY BALANCE IN THERMAL NETWORK MODEL



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OS - OUTER SHELL
B - BOILER SHIELD
PV - PRESSURE VESSEL
SB - SUPPORT BAND
K - CONDUCTANCE
R - RADIATION CONDUCTANCE ($\sigma A \epsilon_{eff}$)
T - TEMPERATURE

ENERGY BALANCE EQUATION FOR VCS NODE i:

$$R_{OS}(T_{OS}^4 - T_i^4) + R_B(T_{Bj}^4 - T_i^4) + R_{PV}(T_{PV}^4 - T_i^4) + K_V(T_{i-1} + T_{i+1} - 2T_i) + K_{SB}(T_{SBk} - T_i) + \dot{M}C_p(T_{i+1} - T_i) = 0$$



Each boiler shield node is connected to the pressure vessel by conduction paths which represent the boiler shield supports. Twelve vapor-cooled shield nodes are connected to the support bands by conduction paths which represent the vapor-cooled shield support struts.

The quantity of fluid expelled from the pressure vessel (\dot{m}) for a given heat leak (q) is given by $\dot{m} = q/\theta_V$ for vapor expulsion and $\dot{m} = q/\theta_L$ for liquid expulsion. The values of θ_V and θ_L are given by $\theta_V = H_V/(1 - \rho_V/\rho_L)$ and $\theta_L = \theta_V H_V$, where H_V is the heat of vaporization, ρ_V is the saturated vapor density, and ρ_L is the saturated liquid density.

7.2.7.5 Constant Pressure Performance Predictions

Heat leaks and boil-off rates for storage of oxygen, nitrogen, hydrogen, and methane with both vapor and liquid expulsion from the pressure vessel were computed for storage pressures from 1 to 10 atmospheres. All computations were made with an external temperature of 530°R.

Figure 4 contains curves of calculated constant pressure mass expulsion rate versus storage pressure for oxygen, nitrogen, hydrogen, and methane with both vapor and liquid expulsion.

Figure 5 contains curves of calculated mass expulsion rate divided by full tank fluid mass versus storage pressure for oxygen, nitrogen, hydrogen, and methane with both vapor and liquid expulsion.

Figure 6 contains curves of calculated heat leak to the pressure vessel versus storage pressure for oxygen, nitrogen, hydrogen, and methane with vapor expulsion from the pressure vessel.

Figures 7, 8, 9, and 10 contain curves of calculated mass expulsion rate versus storage pressure for oxygen, nitrogen, hydrogen, and methane, respectively, with no vapor cooling, with a vapor-cooled shield only, with 82% boiler shield area coverage, and with 100% boiler shield area coverage.

Figure 11 contains calculated curves of temperature of cooling vapor just before it exits the tank versus storage pressure for oxygen, nitrogen, hydrogen, and methane with both vapor and liquid expulsion.

Figure 12 shows total calculated heat leak to the pressure vessel versus effective emittances for the three multilayer blankets. These curves are for oxygen and hydrogen at a storage pressure of one atmosphere.

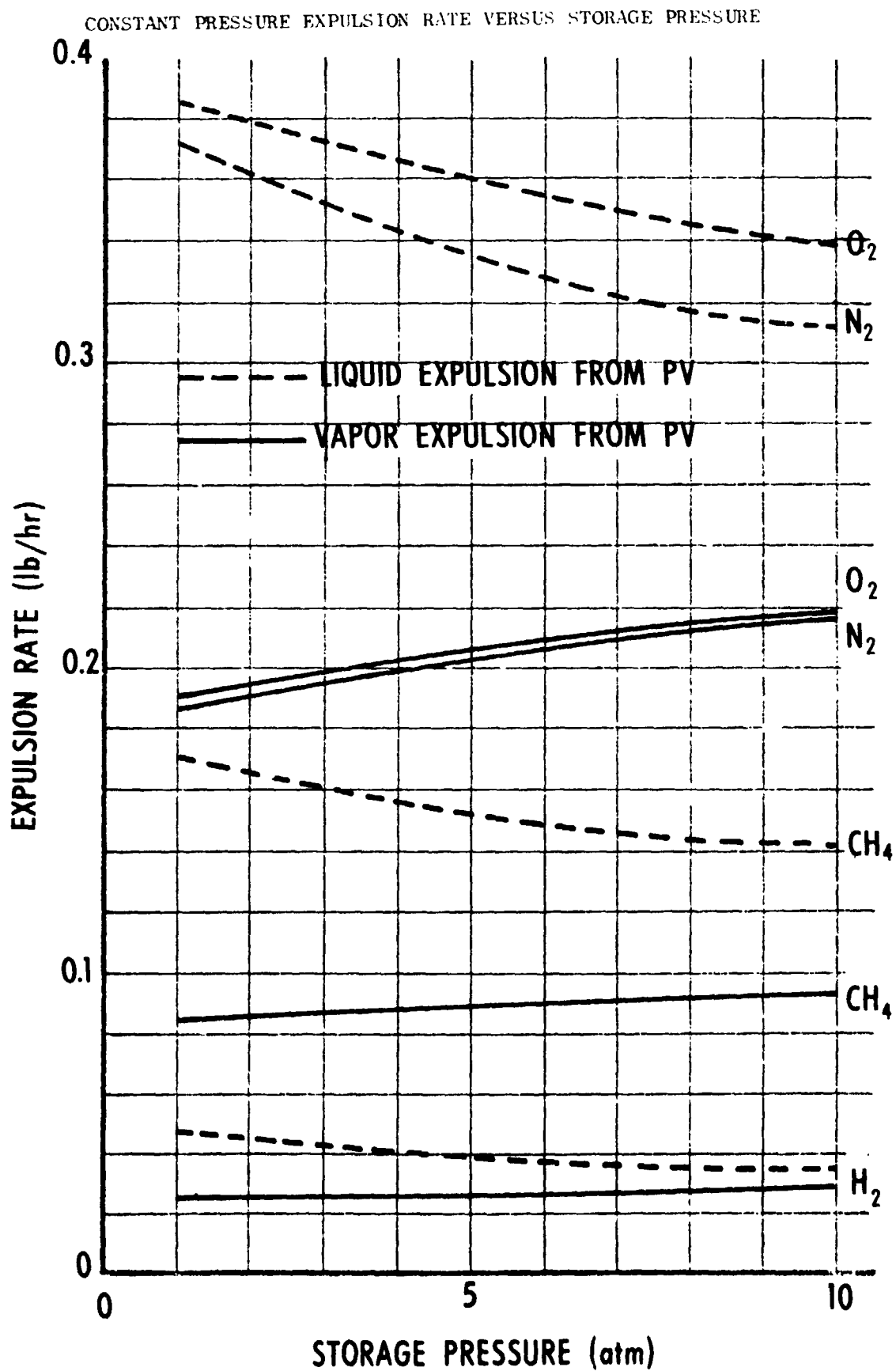
7.2.7.6 Mission Performance Optimization

A study was conducted to maximize the fluid mass after 180 days of storage by allowing part of the heat leak to produce a rise in storage pressures. Computer programs PROXY, PRNIT, and PRHYL were used to investigate the



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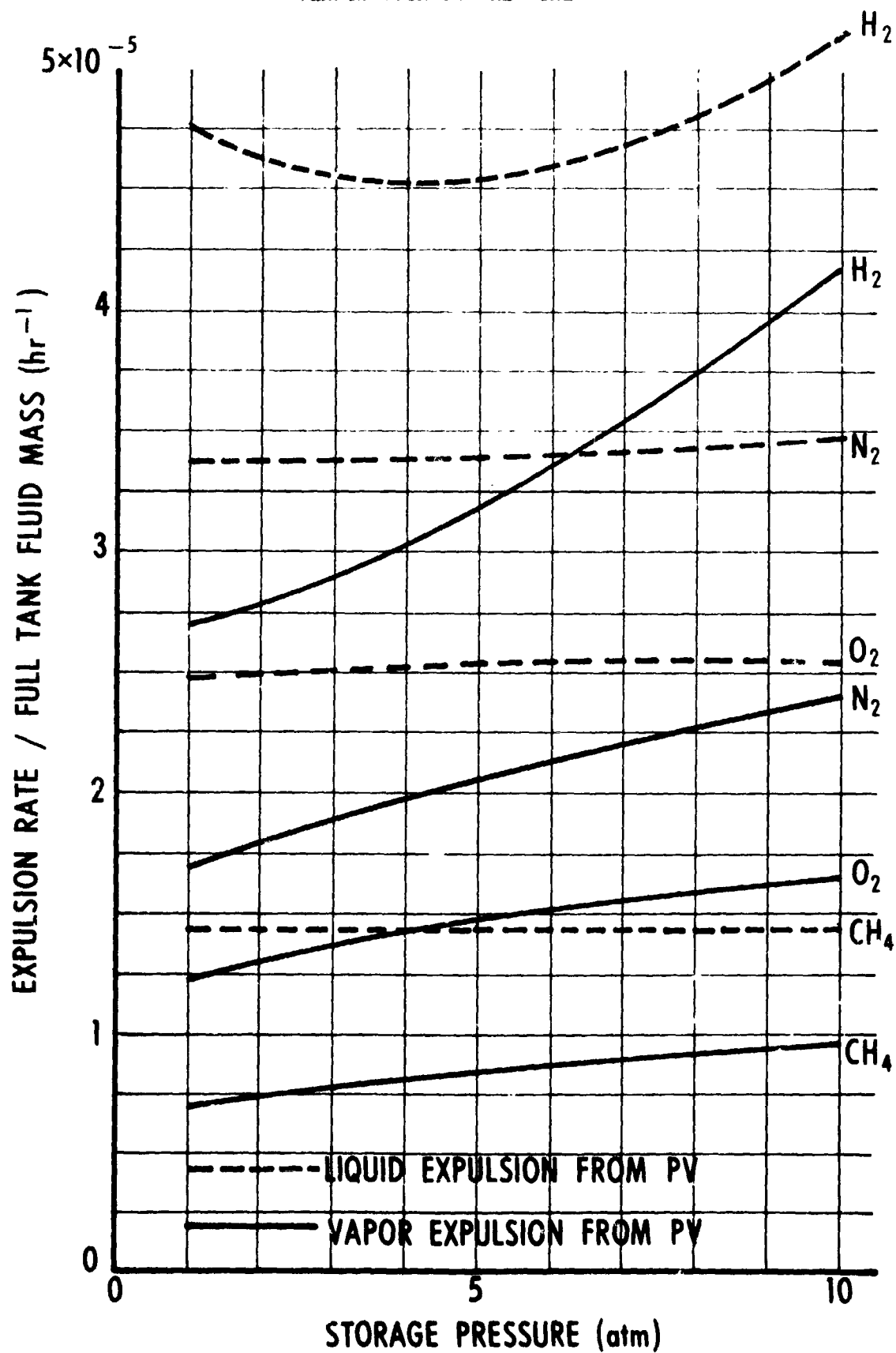
Figure 4





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Figure 5
EXPULSION RATE DIVIDED BY FULL TANK FLUID MASS
VERSUS STORAGE PRESSURE

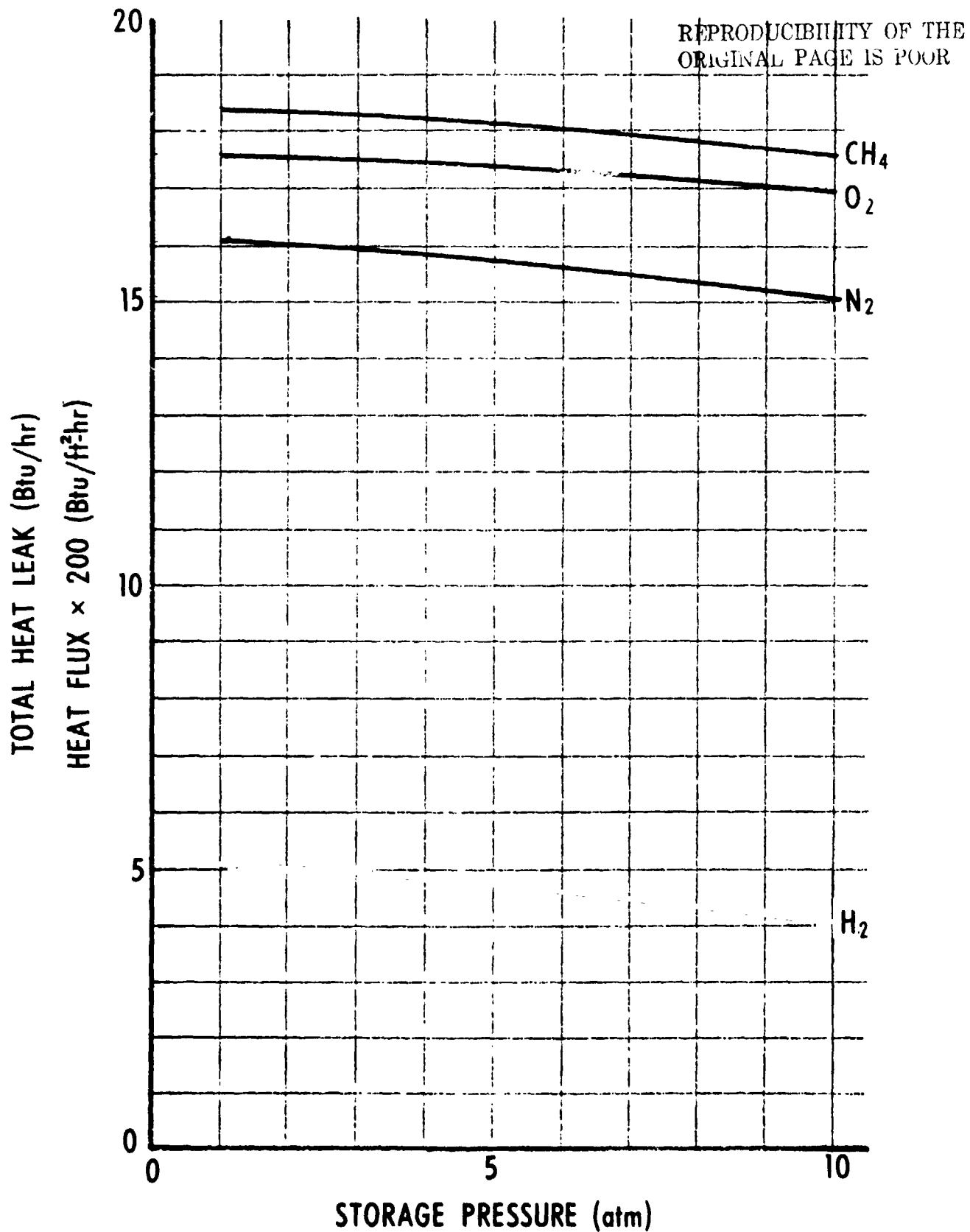




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Figure 6

HEAT FLUX AND TOTAL HEAT LEAK VERSUS STORAGE PRESSURE



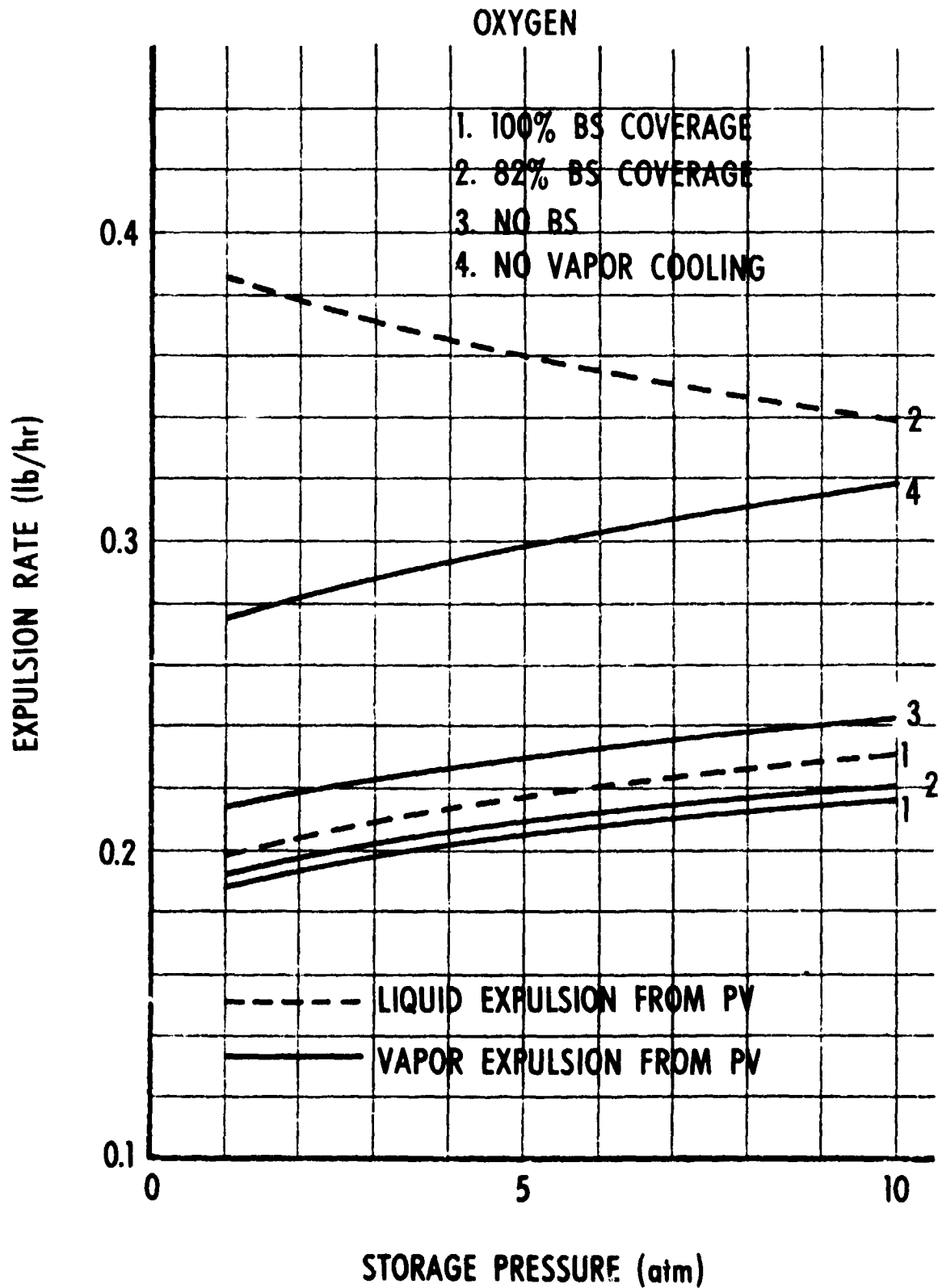


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Figure 7

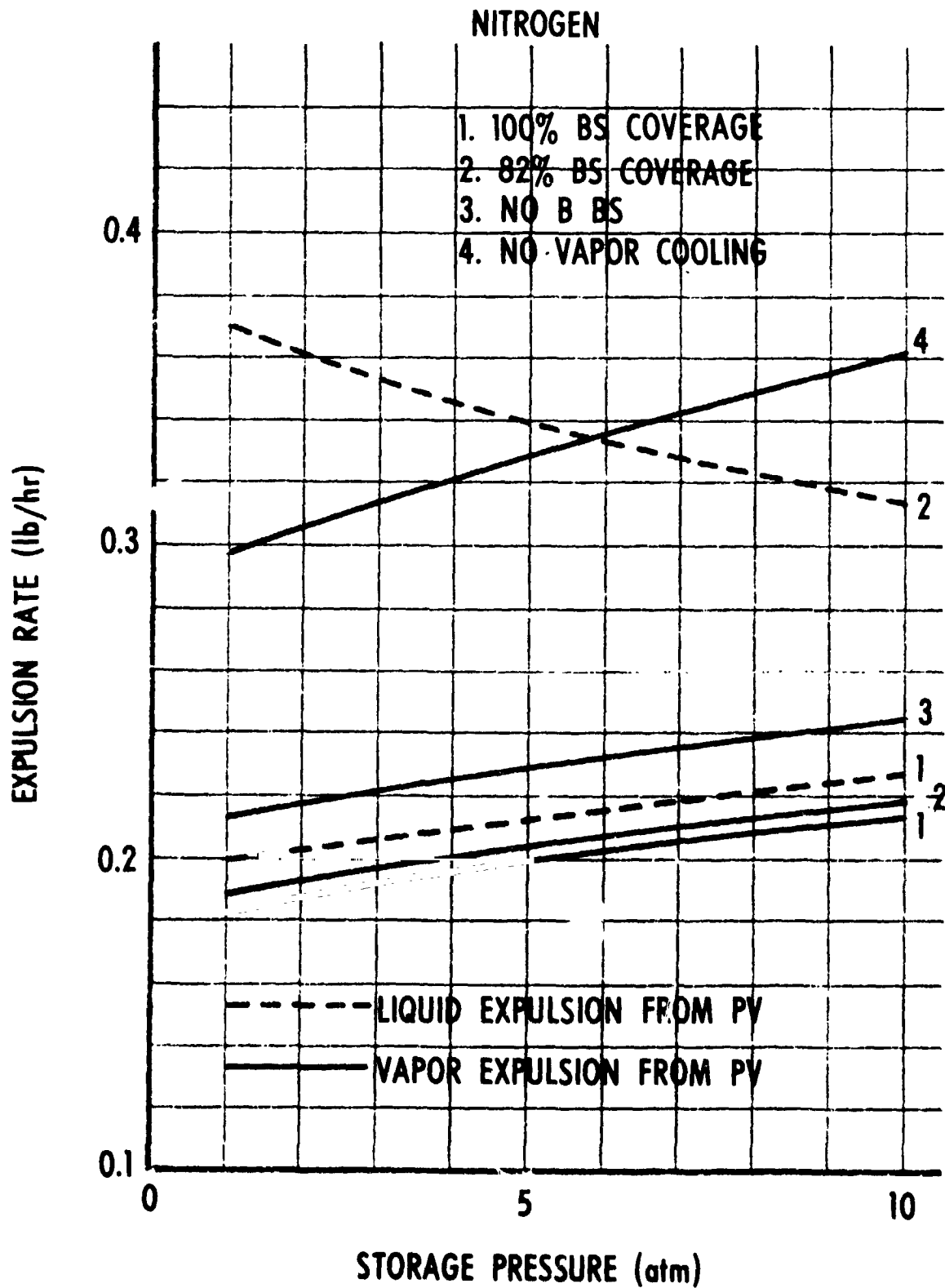
EXPULSION RATE VERSUS STORAGE PRESSURE FOR OXYGEN
WITH FOUR DIFFERENT VAPOR-COOLING CONFIGURATIONS





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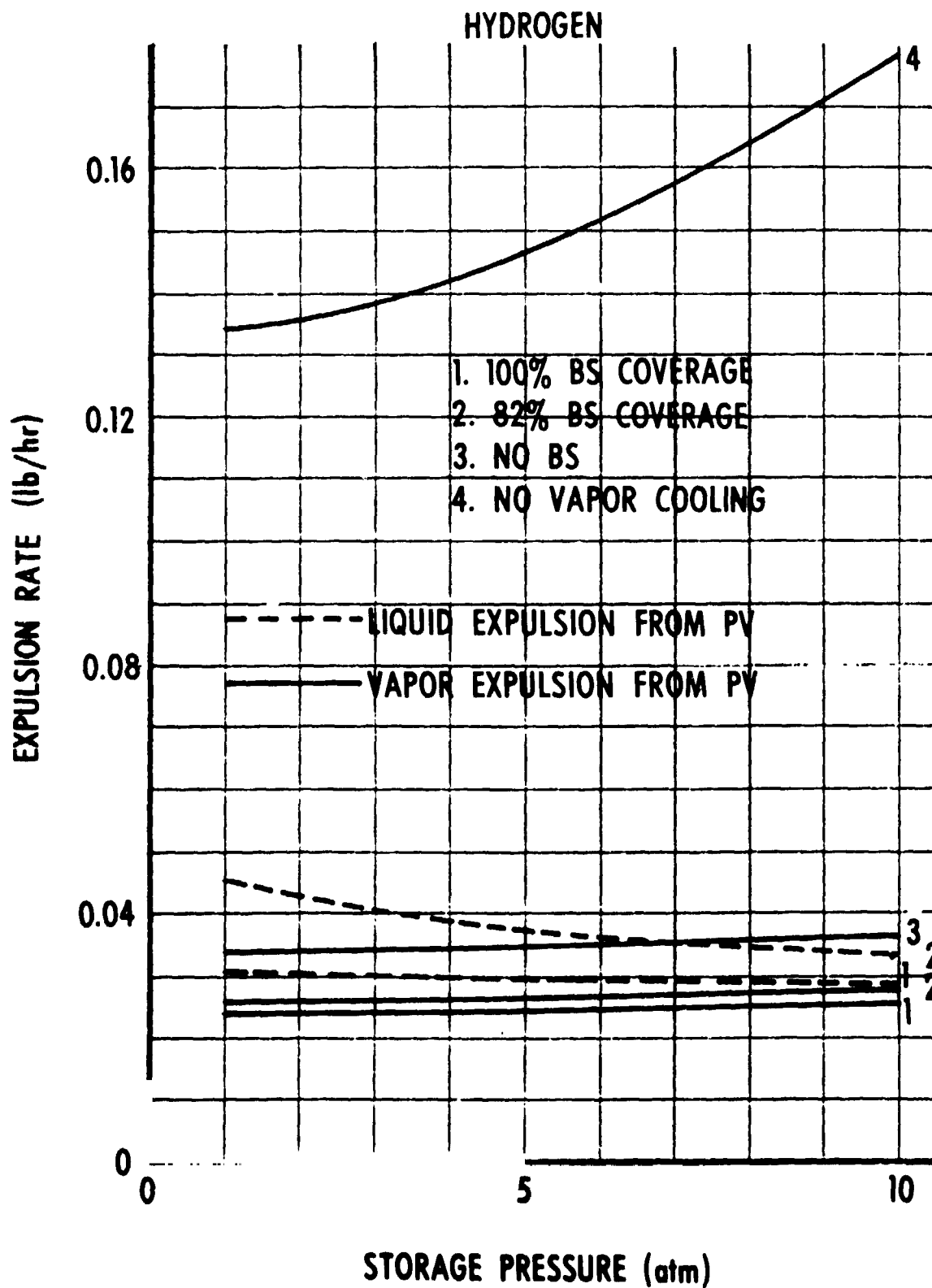
Figure 8
EXPULSION RATE VERSUS STORAGE PRESSURE FOR NITROGEN
WITH FOUR DIFFERENT VAPOR-COOLING CONFIGURATIONS





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Figure 9
EXPULSION RATE VERSUS STORAGE PRESSURE FOR HYDROGEN
WITH FOUR DIFFERENT VAPOR-COOLING CONFIGURATIONS

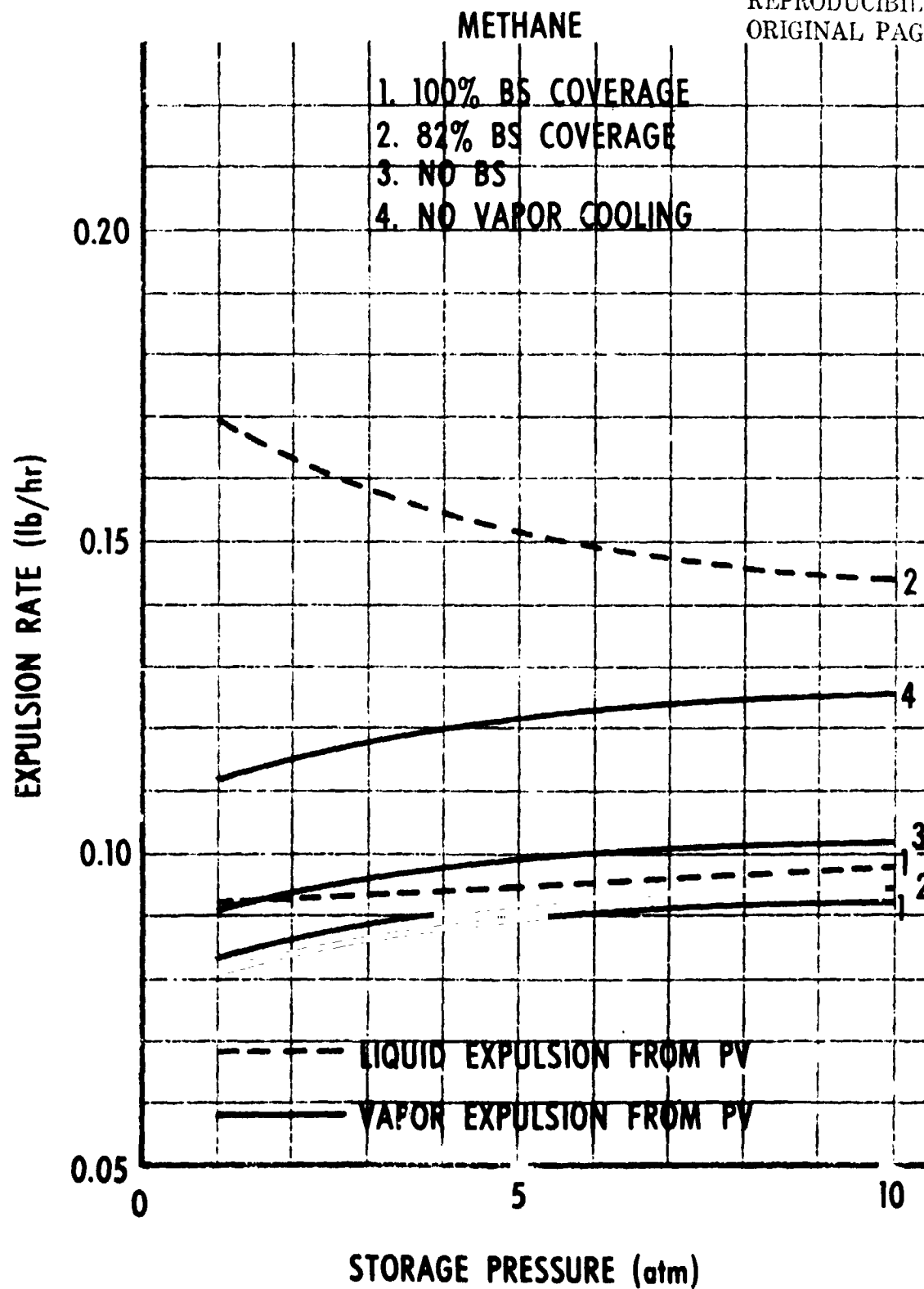




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Figure 10
EXPULSION RATE VERSUS STORAGE PRESSURE FOR METHANE
WITH FOUR DIFFERENT VAPOR-COOLING CONFIGURATIONS

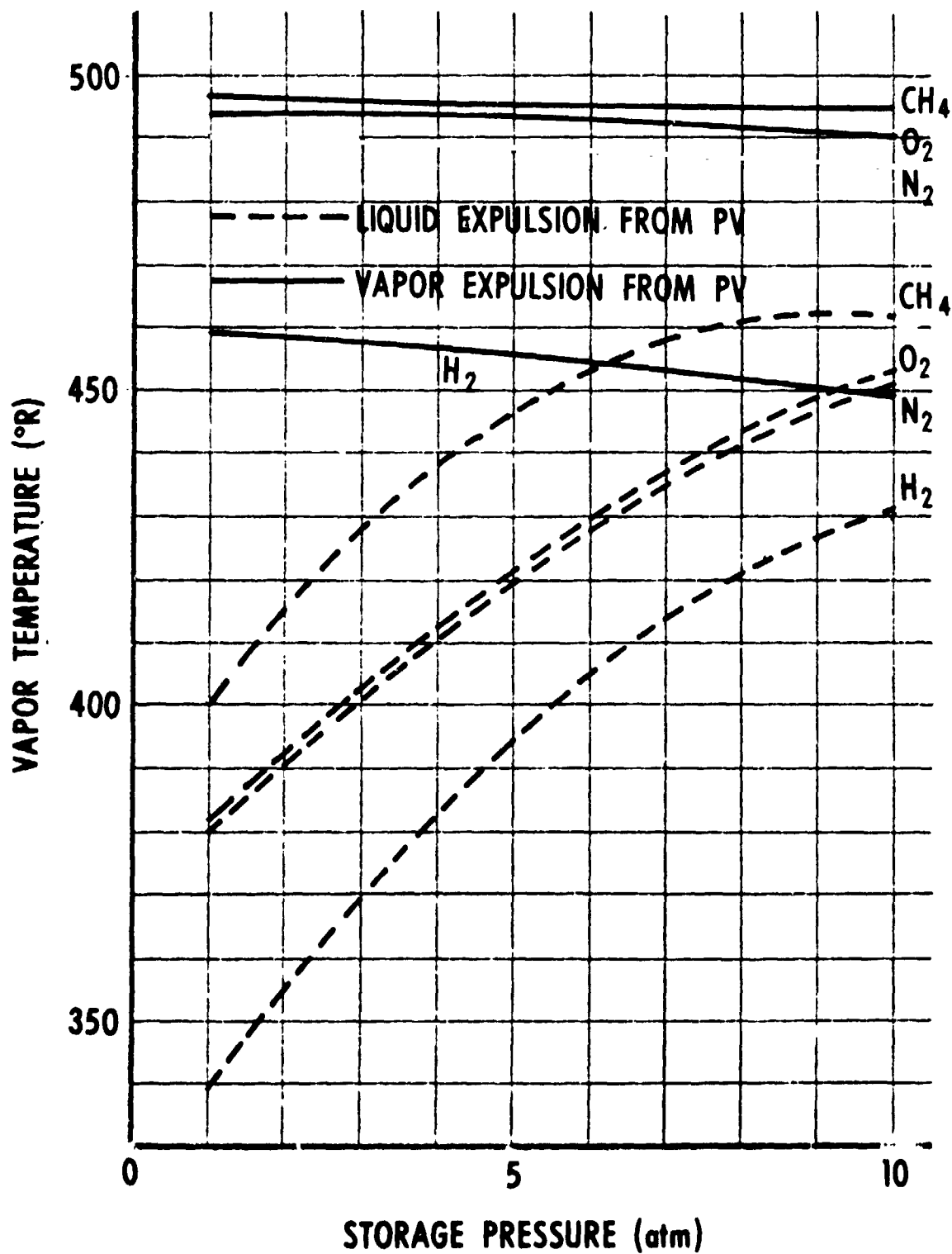
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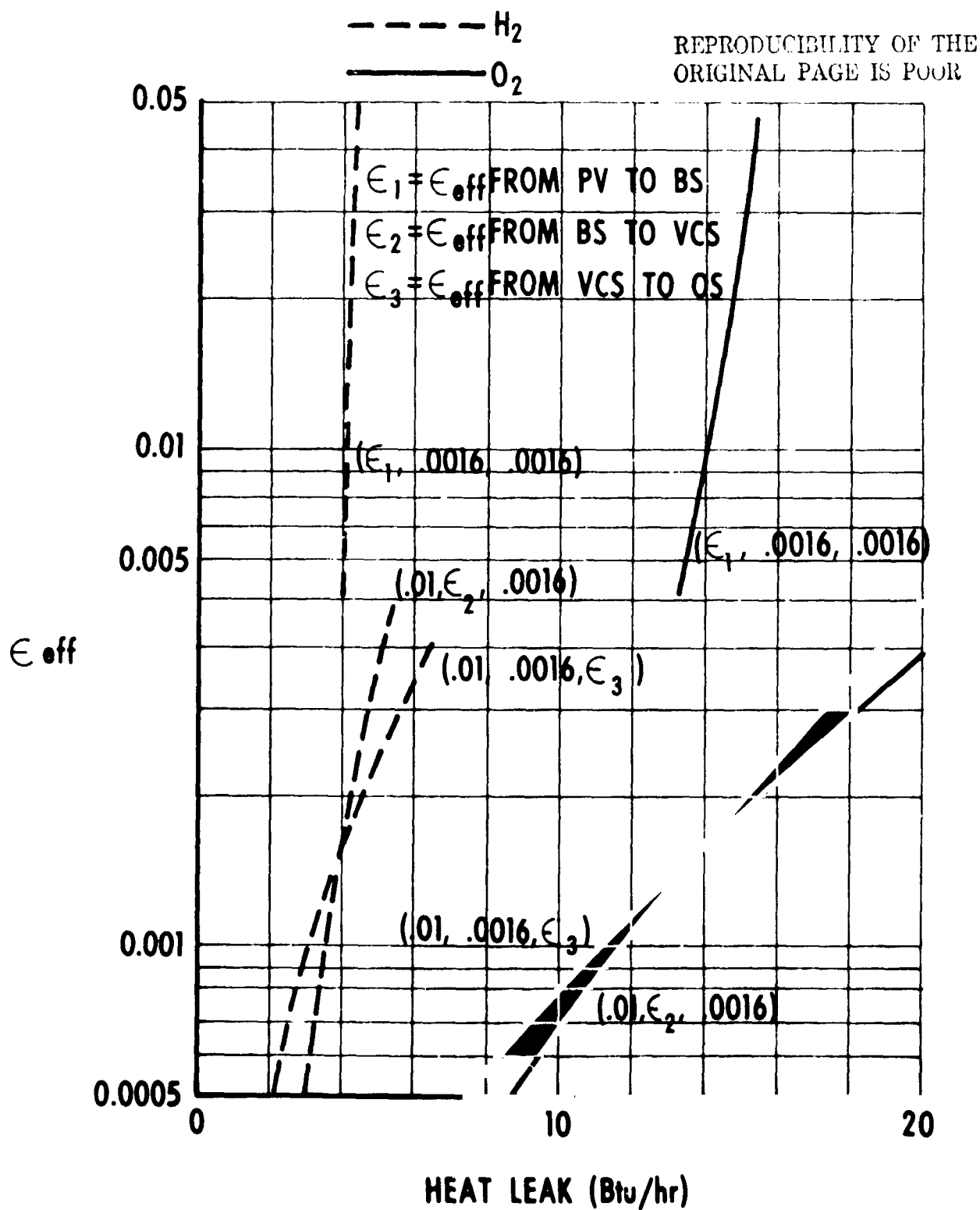
Figure 11
TEMPERATURE OF VAPOR AT EXIT OF VAPOR-COOLING SYSTEM
VERSUS STORAGE PRESSURE





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Figure 12
HEAT LEAK VERSUS EFFECTIVE EMITTANCES OF THE THREE
MIL BLANKETS AT 1 ATMOSPHERE STORAGE PRESSURE





behavior of oxygen, nitrogen, and hydrogen for a variety of fixed expulsion rates which are less than the predicted constant pressure expulsion rates. Expulsion rates were considered to be constant during the mission. While the use of a variable expulsion rate during the mission may provide a very slight improvement in fluid retention, this consideration is beyond the scope of the present work.

These computer programs are restricted to analyzing cryogenic tank configurations with a vapor-cooled shield only. As a result, only vapor expulsion is considered in this work. The absence of the boiler shield has a small effect on the heat leak for oxygen and nitrogen and a larger effect for hydrogen because of its high specific heat. Consequently, the effective emittances of the multilayer insulation blankets were adjusted for this program so that the heat leaks computed with computer programs PROXY, PRNIT, and PRHYL would be consistent with those computed with TAP.

If the fluid expulsion is restricted so that the expulsion rate does not correspond to the heat leak to the pressure vessel, then the pressure, temperature and specific volume of the stored liquid will increase. If the initial ullage or the expulsion rate is too small, the contents will eventually become single phase and the pressure will begin to increase rapidly. For each expulsion rate, there is a minimum initial ullage which is required to prevent the fluid from becoming single phase, and any greater initial ullage will result in less fluid mass at the end of the storage period. The objective, then, is to determine the combination of expulsion rate and initial ullage which will provide the largest fluid mass after 180 days of storage.

Figure 13 contains calculated curves of required initial ullage and fluid mass remaining after 180 days versus expulsion rate for oxygen, nitrogen, and hydrogen.

As might be expected, the optimum expulsion rate is that which the decrease in liquid volume due to expulsion is exactly offset by the increase in liquid volume due to increasing specific volume. In other words, the optimum operation consists of starting with the minimum allowable ullage and controlling the expulsion rate so that the ullage is maintained at that level throughout the mission.

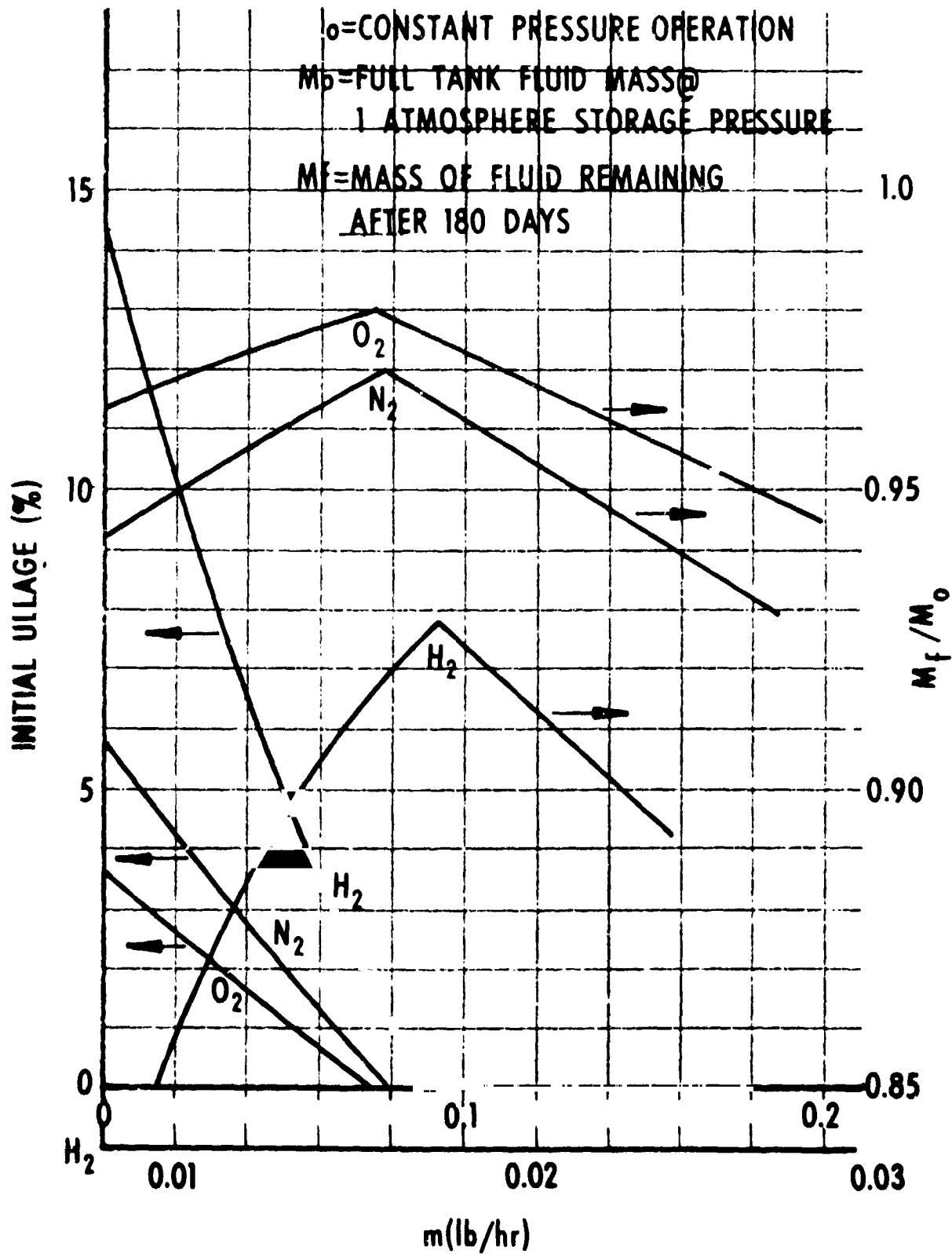
Figure 14 contains calculated curves of storage pressure versus time for oxygen, nitrogen, and hydrogen at the optimum expulsion rates. Notice the difference in the storage pressures of the three fluids at the end of 180 days storage.

The reduction in fluid loss provided by the use of pressure rise is approximately 545, 467, and 36 pounds for oxygen, nitrogen, and hydrogen, respectively. The advantage to be gained through pressure rise is dependent upon the maximum allowable pressure, the length of the mission, the heat leak rate, and of course, the fluid. The design mission requirements for this tank, i.e.



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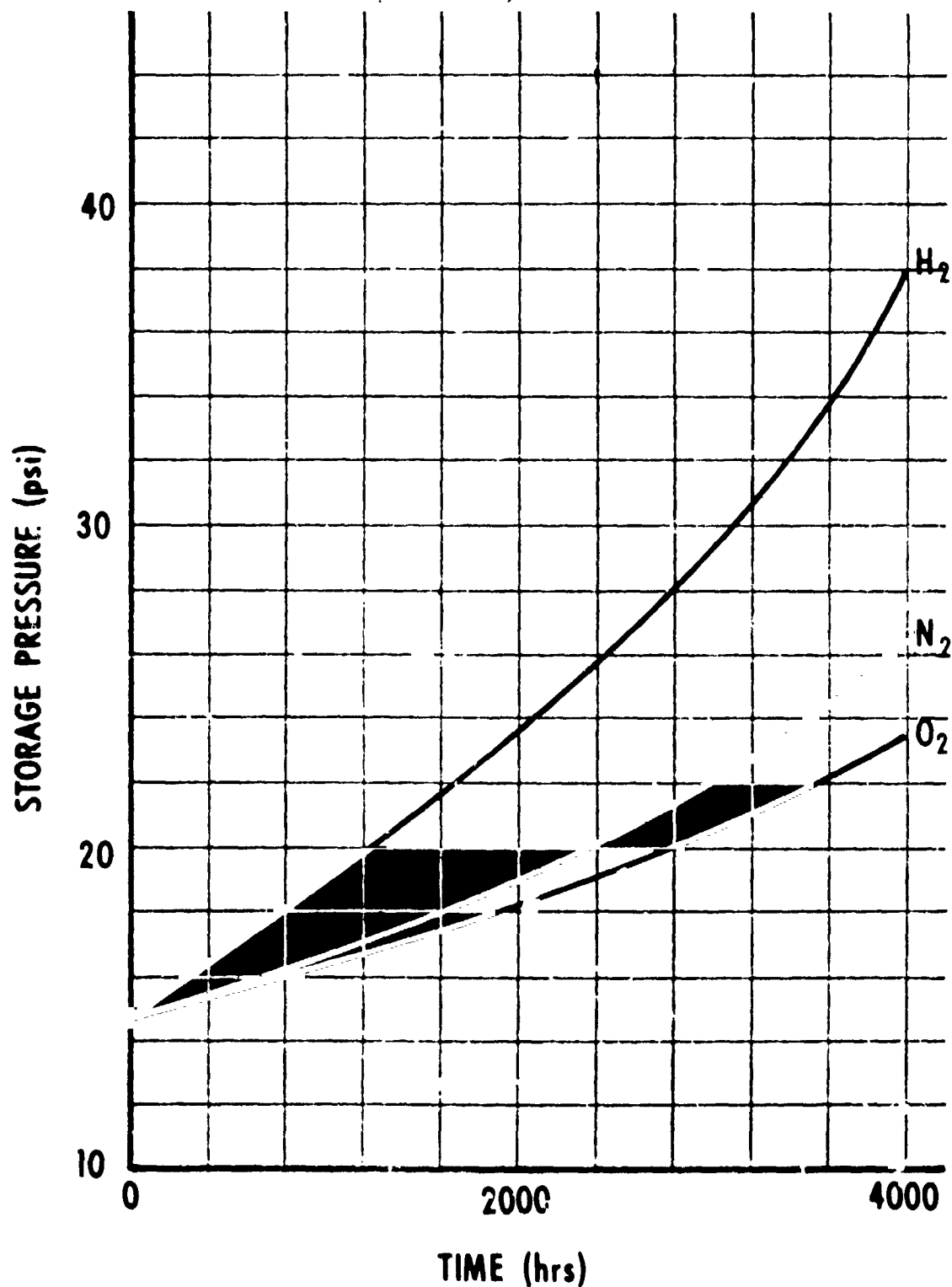
Figure 13
REQUIRED INITIAL ULLAGE AND FLUID MASS
REMAINING AFTER 180 DAYS VERSUS EXPULSION RATE





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Figure 14
STORAGE PRESSURE VERSUS TIME AT OPTIMUM EXPULSION RATE
FOR
OXYGEN, NITROGEN, AND HYDROGEN





long storage period, high operating pressure (150 psi) and low heat leak to stored mass ratio, are all conducive to improvement of fluid retention through utilization of pressure rise.

7.3 Structural Design and Analysis

The analysis work in this category performed for the prototype spherical cryogen container is detailed in Beech Report ER 15423. Since the purpose of the prototype was primarily a thermal test article, the design of the unique band suspension system and the pressure vessel has not been optimized from a material and weight standpoint. However, sufficient analysis has been performed to permit future optimization in the next design iteration.

7.3.1 Pressure Vessel

2219 aluminum was selected for the prototype pressure vessel because of its compatibility with the five possible cryogens, its excellent weldability, good mechanical properties, and the substantial amount of experience that the aerospace industry has gained in the use of this alloy.

The aluminum hemispheres were spin-formed in the O-condition at the Beech-Wichita facility. A thermal treatment was then given to bring the material to the T42 condition. The preliminary design allowables used in the analysis were as follows:

(a) Parent Material - 2219-T42

$$F_{tu} = 50,000$$

$$F_{ty} = 25,000$$

(b) Weld Material (as welded)

$$F_{tu} = 27,000$$

$$F_{ty} = 16,000$$

Assuming mismatch factor
of 0.90 (15% mismatch)
and porosity factor of
0.85.

After fabrication of the hemispheres, test coupons gave the following properties:

(c) Parent Material - 2219-T42

$$F_{tu} = 50,000$$

$$F_{ty} = 24,000$$

3/8-inch t



(d) Weld Material

$$F_{tu} = 34,000$$

1/16-inch offset

$$F_{ty} = 18,000$$

No unusual design or stress conditions were imposed on the pressure vessel other than those due to the external pressure of the support bands.

Stress levels introduced into the pressure vessel were computed by use of coefficients determined from a computer study conducted by Beech Aircraft Corporation. The maximum stress in the 0.36-inch thick vessel material under the pads was 15,200 psi which includes the direct bending stress due to concentrated loads and internal pressure.

Stress levels were also computed in the pressure vessel where the bands contact the shell through 7-inch-wide aluminum shoes. A maximum stress of 12,200 psi was found which is slightly less than the stress computed under the pads.

7.3.2 Suspension System

The suspension system is a departure from convention and consists of three circular rings of filament-wound fiberglass interwoven in assembly to produce a multidirection support for a spherical shape, as shown in Figure 15. Each circular section is provided with two diametrically opposed tangential extensions to form the external load supporting attachments. The vessel support rings and extensions are wound as an integral one-piece element. Bands are separated from the pressure vessel surface by fiberglass pads and aluminum shoes. The purpose of the pads is to add thermal resistance in series with bands. The shoes distribute the line loading of the bands on the surface of the pressure vessel.

The three interlaced fiberglass bands effectively form a basket ("woven") around the pressure vessel. In supporting the vessel, inertial forces are distributed to the system of bands proportionally with respect to the angle of load application. Individual bands are not required to carry the full loading at any time. The structural support extensions extend from the encircling fiberglass band in a tangential direction which provides a maximum length heat path and an efficient tension loading direction. Since the function of the complete assembly is to store cryogenic fluid with a minimum loss, the three-ring design suitably matches the needs by providing low heat transfer and high efficiency in structural loading reaction.

Support extensions are designed to attach to a single equator ring. The contact angle of the bands with the equator ring is established on the basis of the directional loading expected as established by specification and end use of the assembly. The relationship of the vertical and side loads determines the angle required to uniformly support the vessel. Attachment of the

OTTA
Oxygen Thermal Test Article
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Figure 15

**REPRODUCIBILITY OF THE
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PV Plug (north pole)
Vent Line Guide Retainer
Vent Line Guide

Pressure Vessel
Insulation Pad

Support Band Shoe
Support Band

Vacuum Pump

220/440 VAC Plug

Vacuum Valve

Girth Ring
Vacuum Relief Valve
Electrical Connector

Electrical Connector
Ionization Tube

Vapor Discharge Line Filter

Vapor Discharge Line

Outer Shell (north polar)

Vapor Discharge Line

Vapor Cooled Shield
(VCS north polar)

Boiler Shield (north polar)

Boiler Shield

Boiler Shield

Vapor Discharge
Vent Location
Fill Location
Rotation
Trunnion Bearing

VCS (Equator Section)

Vent Line

Rupture Disc Assembly

Vent Connection

Pressure Relief Valve

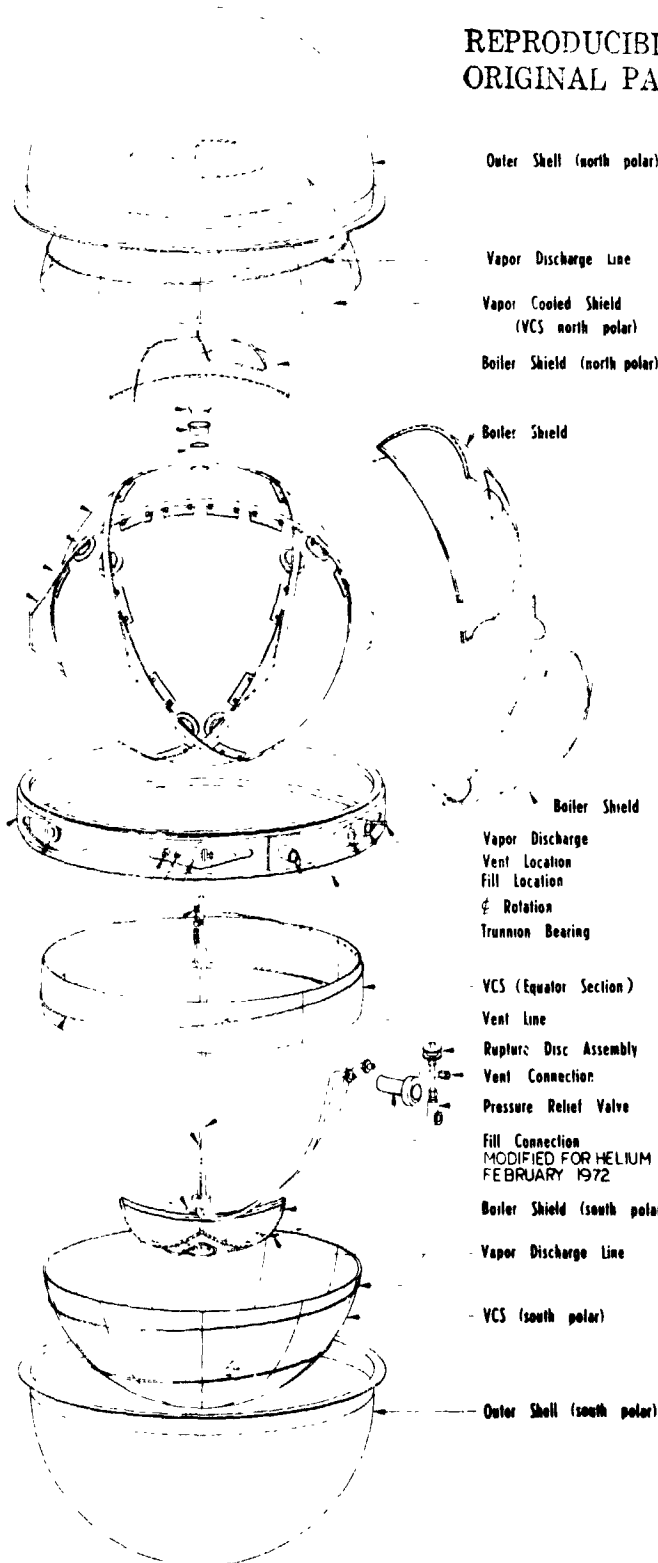
Fill Connection
MODIFIED FOR HELIUM
FEBRUARY 1972

Boiler Shield (south polar)

Vapor Discharge Line

VCS (south polar)

Outer Shell (south polar)





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support bands to the girth ring is accomplished by a simple bolted connection with the bolts passing through a reinforced section of the band extension into the girth ring. The attachment land on the girth ring is machined at the proper orientation to provide a smooth flat surface mounting for the band extension. Loading of the band is considered to be effectively in straight tension even though minor moments are actually reacted by the band stiffness.

The circular portion of the support bands is wound to a diameter that is slightly greater than the diameter of the vessel to be retained. This allows for adjustment to manufacturing variations at the time of assembly. Load distributing "shoes" are installed between the vessel and bands. Twelve (12) support pads are symmetrically located about the axes and the "shoes" are uniformly spaced between the pads. Flat aluminum shims are used at the support pad and "shoe" locations to develop the necessary preload in the bands.

Each of the three continuous circular bands is inclined 30° from the vertical axis of the pressure vessel. The rings are oriented 60° from each other at the attachment location to a circular girth ring. The girth ring lies in a horizontal plane at the equator of the vessel.

The method of analysis used for investigation of this suspension system assumes no bending stiffness in the bands. Starting with the blueprint geometry, the load factors were applied to the vessel geometric center. Simple equations of statics were used to compute the band loads and support pad forces. Deflections at nodal points were calculated which revised the action line of forces resulting in small adjustments in force magnitude. Calculations assumed that no shearing forces pass through the band/pad/shell interfaces. The addition of friction forces at the interfaces had the effect of reducing band loads. Internal loads resulting from axial external loading of $7g \times 17,300/3 \cos 30^\circ = 46,600$ lb for $n_z = 7$, and side loading of $3g \times 17,300/1.5 = 34,600$ lb for $n_x = 3$, where the 1.5 factor accounts for the restraint provided by out-of-plane bands.

Preload in the bands was designed to develop 12,000 psi. Maximum loading of 77,600 psi occurred in the bands with a loading combination of 3.5g axial (n_z) and 3.0g side (n_x). In this condition the maximum pad load was 17,380 pounds resulting in a uniform pad loading of 615 psi. This is based on zero friction force at the pad interface. To verify the capability of the pad material to resist shearing forces resulting from friction, a component test was performed on a representative pad by imposing an 18,000-pound axial load in combination with an 1,800-pound shear load. There was no evidence of failure of any kind. The addition of a friction force has the effect of reducing the band loads as shown in Table 1.

The stress levels introduced into the pressure vessel were computed by use of coefficients determined from a computer study conducted by Beech Aircraft Corporation. The resulting member loads are tabulated in Table 4 included in Appendix A.



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Table 1
LOAD LIMIT

Type	M ₁ In-lbs	V ₁ lbs	T ₁ Kips	M ₂ In-lbs	V ₂ lbs	T ₂ Kips	S. F.
One Time	745	53	69.5	935	67	44.5	1.5
900 Cycle	765	54	57.0	860	61	44.5	Not Specified

The maximum stress level in the 0.36 thick parent material under the pads is 15,200 psi which includes the direct and bending stresses due to concentrated load and the stress due to internal pressure.

$$M.S. = \frac{25,000}{15,200} - 1 = + 0.64 \text{ on yield}$$

Deflections in the pressure vessel were compared with deflections in the 10-inch diameter plate and found to be compatible, thus verifying the assumption of uniform pressure.

Stress levels were also checked in the pressure vessel in the areas where the bands contact the shell by means of 7-inch-wide aluminum shoes. Maximum stress levels computed were 12,200 psi, slightly less than those computed under the 10-inch diameter plates.

The plates and shoes were checked for uniform loading. Results indicated stress levels approximately equal to 28,500 psi. The margin of safety for the 6061-T6 material is:

$$M.S. = \frac{35,000}{28,500} - 1 = + 0.37 \text{ on yield}$$

The stability of the pressure vessel, under a concentrated load, was checked by referring to a study by Bushnell (Reference 6.3).

The support ring assemblies are designed to meet the following requirements:

- (1) Support a spherical pressure vessel with 225 ft³ capacity.
- (2) Attachment reactions per Table I and Figure 16.
- (3) Vessel to contain LO₂, LH₂, LN₂, or methane.



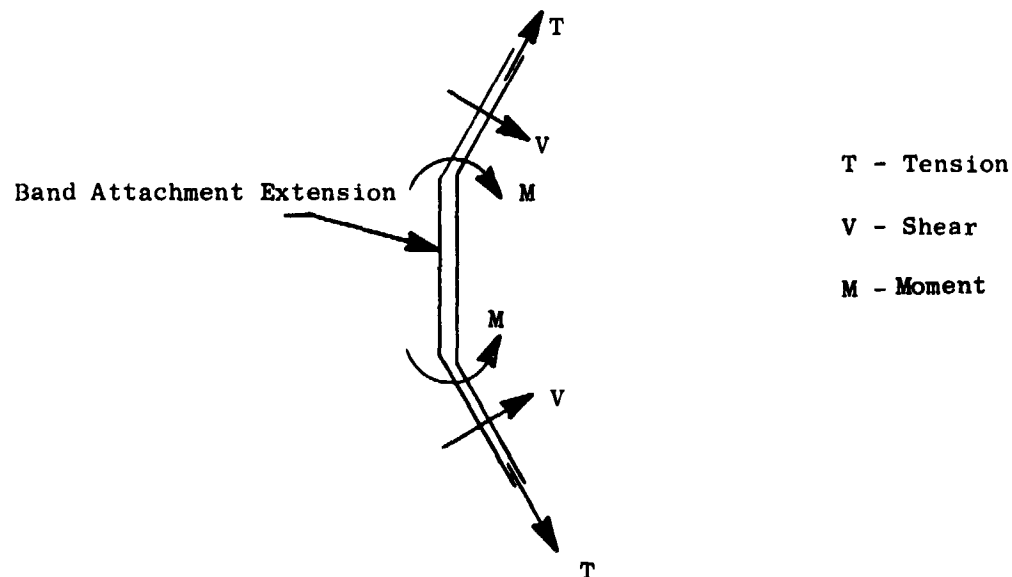
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- (4) Provide a low thermal conductivity.
- (5) Operating requirements:

Vacuum Pressure - 1×10^{-7} mmHg

Temperature - 65°F to $+140^{\circ}\text{F}$

Figure 16. BAND FORCES



- (6) Minimum weight compatible with #2 and #4 above.
- (7) Acceleration load factors shall be those used for the design of the cryogenic storage subsystem on the Apollo Program.

$N_x = +7, -3$ where the positive sense is aft directed, (see note),

$N_y = N_z = \pm 3g$. A combined load factor of $n_x = +3.5g$ and

$N_y = N_z = \pm 3g$.

NOTE: Positive sense is downward in normal position as shown in Drawing 460966A.



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- (8) The system shall be designed to withstand normal shipping with no damage.
- (9) The design weight used in the analysis was 17,300 pounds. This was derived from

$$\begin{aligned} 225 \text{ ft}^3 \times 71.14 \text{ lb/ft}^3 &= 16,000 \text{ pounds LO}_2 \\ \text{Pressure Vessel \& Hardware} &= \underline{1,300 \text{ pounds}} \\ &17,300 \text{ pounds} \end{aligned}$$

Fiberglass material was selected for the band construction because of its high strength and relatively low coefficient of thermal conductivity. The mechanical properties used for design are shown below.

Materials

Glass: S/HTS glass filament to weapons specifications WS 1126.

Resin: Epoxy formulated for cryogenic service (Resin No. 2, NASA Contract NAS 3-6287).

Composite Construction and Density

Filament Orientation:	Unidirectional circumferential continuous filament windings.
Filament Fraction in Composite:	70% Volume, 82% Weight.
Resin Fraction in Composite:	30% Volume, 18% Weight.
Composite Density:	0.075 lb/in ³ (75°F).

Mechanical Properties

Ultimate Tensile Strength Allowable

Composite (based on total cross-sectional area)	220,000 psi
Filament (based on equivalent filament cross-sectional area)	315,000 psi

Modulus

Parallel to direction filaments:	8.7×10^6 psi
Perpendicular to direction of filaments	1×10^6 psi



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Poisson's Ratio

0.25

Thermal Expansion (70 to -400°F) (from Curve)

Parallel to direction of filaments

7×10^{-6} in/in °F

Perpendicular to direction of filaments

1.4×10^{-6} in/in °F

The material used for insulating pads is an E glass (designation by manufacturer) with a binder. The bulk material is stacked, pressed to one inch thickness and cured at approximately 450°F for two hours. The resultant is a one-inch-thick six-inch diameter compressible pad.

7.4 Instrumentation

Since the primary objective of the program was to develop a dewar for extended mission (180 days) capability, instrumentation was kept to a minimum.

7.4.1 Temperature

Eight platinum resistance thermometers are installed in the evacuated annulus space. Schematic location of the thermometers is shown on Drawing 460992.

Identification
Number

Location

TS-23	On vapor-cooled shield tube discharge from boiler
TS-24	On fill line as it leaves the pressure vessel
TS-25	On pressure vessel at the normal top pole
TS-26	Center of flow pattern on vapor-cooled shield
TS-27	Directly over one support pad on the outside surface of the fiberglass band
TS-28	On outside surface of fiberglass band between two support pads in the normal top polar region
TS-29	On vapor-cooled shield line as it discharges into the girth ring from the evacuated space
TS-30	On vapor-cooled shield line as it discharges from the vapor-cooled shield



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Temperature sensors are manufactured by Rosemount Engineering Company, (REC). They are Model 118-347-3 and cemented in place using REC cement #5924.

External temperatures are to be measured by use of test facility equipment.

7.4.2 Pressure

Two pressure gages are located in an external control module (Drawing 660995). Internal tank pressure is measured at the vapor flow port and the vent port (see schematic Drawing 460992) when the control module is in use. Gages are manufactured by Ashcroft Duragauge Company. The gages are identical, Model 45-1377SC, 4 1/2-inch face, and measure pressure from 30 inches Hg vacuum to 300 psi (Drawing 660995).

Vacuum pressure is measured with an ionization tube, Model 274003K manufactured by Granville-Phillips Company. Vacuum pressure may also be determined during operation of the 30 liter/second Noble Vac-Ion pump, Model 911-5032, purchased from Varian Company. The Vac-Ion pump is furnished with a controller unit which provides a means of measuring the vacuum level as well as supplying the high voltage to the ionization probe.

7.4.3 Quantity of Propellant

No internal instrumentation is provided for measuring the quantity of propellant inside the pressure vessel. A weighing system consisting of four (4) load cells, one (1) summing box, and one (1) transducer indicator is furnished. Tare weight must be established prior to each propellant loading.

The coordinated weighing system is manufactured by BLH Electronics Inc. Each load cell, model C3P1, has a range of 0 - 5000 pounds. The summing box, model 308, contains the electronic circuitry that adds load cell values and sends a cumulative signal to the model 8000 read-out box. Weight is shown in pounds in the nixie tube display.



8.0 CAPABILITIES

In meeting the objectives of the OTTA program, a unit was produced that provides a multipurpose test-bed for any number of insulation systems. The outer shell is conveniently removable since there are no plumbing penetrations or attachments to the spherical sections. The plumbing and suspension elements attach to or pass through the single girth ring. With the spherical shells removed, the entire annular insulation cavity is accessible for removal and reinstallation of insulation materials.

The OTTA system is designed to accommodate a wide range of storage pressures (0 - 150 psia) and operational conditions.

Specifically the OTTA offers the following capabilities:

- (A) Use with liquid nitrogen, oxygen, hydrogen, methane, or helium.
- (B) Storage and operating pressure from zero to 150 psia.
- (C) Suitability for testing in temperature environments from -65°F to 140°F .
- (D) Liquid oxygen flow rate of 10 lb/sec.
- (E) Suitability for changing the insulation system to test specific thermal protection objectives.
- (F) May be positioned for vapor or liquid withdrawal through the vapor-cooling system.



9.0 TEST

9.1 Type of Testing

Thermal design verification testing is the only type of testing that has been performed on OTTA. Test fluids used were liquid nitrogen, liquid hydrogen, and liquid helium. The tank was installed in a controlled environment which was maintained at 70°F or 75°F.

9.2 Objective of Testing

The purpose of the testing was to determine the effectiveness of the thermal protection system.

9.3 Summary of Testing

Liquid nitrogen testing was first begun during the last week of August 1971. The initial test was to determine the nominal heat leak and was completed on October 22, 1971. Since the OTTA thermal protection system was considered to be experimental, a period of time amounting to 18 days was used for engineering observations before starting the 1971 steady-state heat leak test. This period of time provided opportunity to adjust, check, and calibrate instrumentation and mechanical components, as well as observe the thermal effects on the vacuum maintenance system and pressure vessel supports. The steady-state heat leak observations was started on September 16 1971 and continued for 36 days. At the end of the heat leak test the contents were pressurized for a rapid depletion test. The heat leak was observed to be 13.1 Btu/hr under constant pressure and environmental temperature conditions. A vacuum annulus pressure of 4×10^{-5} mmHg was dynamically maintained during this test period.

The second exposure that OTTA had to liquid nitrogen came after approximately 10 months of required delay while an internal vacuum leak was repaired and an external modification was made to the fill line connection. This second test was performed in such a manner that the constant pressure level was approached by decreasing pressure from the fill level. Whereas, the first test involved an increasing pressure to the desired constant pressure level. The 1972 test was performed using effectively a static vacuum. Heat leak was monitored for 49 days but "officially" recorded for only a 4-day period after the insulation system temperatures had stabilized. The results of this test showed a significant improvement in heat leak to 8.4 Btu/hr.

A few days after the end of the "official LN₂ boil-off test" the vented flow was stopped creating a "no-flow" condition for observation. Pressure was allowed to rise for 18 days.

The third cryogen exposure for OTTA was with liquid hydrogen. This test was actually intended as a cool-down step in preparation for a liquid helium fill. However, the hydrogen exposure was maintained for a sufficient amount



of time to reach a reasonable thermal stabilization so that a practical heat leak could be established. The resulting heat leak was 4.45 Btu/hr.

Liquid helium was transferred into OTTA on November 3, 1972. The boil-off rate was continuously monitored during stabilization which required approximately 24 days. After the "official LHe boil-off test" the tank was continuously monitored for a period of two months in a minimum loss condition. During the remaining two and one half months of observation various thermal reactions were observed with and without the use of the VCS, in the no-flow condition, and at supercritical pressure levels. Results of these tests are charted in Figures 22 and 23.

9.4 Test Procedure

The testing that was done at the Beech-Boulder facility was performed according to test procedures BP 15438 or BP 15534 for liquid nitrogen and BP 15551 for liquid hydrogen and liquid helium. The test procedures cover all steps in preparation up through the heat leak using the vapor-cooled shields. Engineering investigation tests that have been performed were directed by W. L. Chronic on a less formal basis with a log record of the steps taken.

9.4.1 Conditions of Testing

The OTTA was installed in a specially constructed chamber to maintain a temperature environment of 70°F to 75°F. During the "official" tests no adjustments or repairs were made to the unit.

In 1971, prior to the "official" test run, a minor leak was discovered in the vacuum annulus. Engineering investigation tests were performed to determine the magnitude of the leak and whether the attached pumping system would be sufficient to overcome the leakage to maintain an adequate vacuum level. Positive results allowed the test to proceed under dynamic vacuum pumping. Subsequent to the 1971 LN₂ tests the vacuum annulus was opened, the leak found, and the faulty part replaced. A failure analysis is recorded in Beech Report ER 15507.

9.4.2 Instrumentation

A list of instrumentation is included in each test procedure. All Beech equipment is calibrated at specified intervals against standards traceable to the United States Bureau of Standards.

Tank vacuum, internal pressure, outflow rate, and gas temperature were visually observed and recorded manually in the 1971 test. These same parameters were observed and recorded in the same way in 1972 and in addition the tank pressure and outflow rate were electronically recorded.

Temperature of insulation components, environmental chamber, and dewar skin were electronically recorded.



9.4.3 Tests and Discussion

The following tests have been performed:

- (A) Continuity Test - Temperature Sensors
- (B) Continuity Test - Strain Gauge
- (C) Vac-Ion Verification
- (D) Thermal Performance - LN_2 (1971, 1972)
- (E) Thermal Performance - LH_2 (1972)
- (F) Thermal Performance - LHe (1972)
- (G) Tank Depletion - LN_2 (1971)

Tests (A), (B), and (C) above are electrical verification of operability for the equipment noted. The Vac-Ion pump performance during the 1971 test series was not altogether satisfactory since the total operating time to failure was only 353 hours. Normal life for the Noble pump is at least 20,000 hours. The Vac-Ion pump was not used during the thermal performance testing in 1971. Discussion with the manufacturer on the Vac-Ion failure indicated that the observed condition (termed failure) may only be a temporary shorting of the plates due to having operated in a nitrogen atmosphere above 1×10^{-4} mmHg pressure for a short period. This condition was later confirmed when the pump was sent to the factory for repair.

The thermal performance tests (D), (E), and (F) above are graphically represented in Figures 18, 19, 20, 21, 22, 23, and 24 which show the full testing sequence that was followed including the effects of cool-down and stabilization.

For the liquid nitrogen test of 1971 (Figure 18) the OTTA was filled a low pressure (12.5 psia) and then allowed to build pressure slowly to the desired test level. The test pressure was 760 mmHg. This method of approach causes a very gradual temperature stabilization to occur since the flow through the vapor-cooled shield is restricted while pressure is building in the pressure vessel. In 1972 the vapor-cooled shield flow channel was allowed a full flow during filling which cooled the insulation system at a very rapid rate. It is very easy to overcool the shielding using the second method which can cause a delay in temperature stabilization. Fill pressure (1972) was maintained above the desired stabilization level to provide a positive pressure control while adjustment was made to the desired level. When hydrogen was introduced into the OTTA, the vapor-cooled shield temperature was manipulated to a precalculated level in an attempt to reduce the stabilization time. The boiler shield temperature became colder than desired while the vapor-cooled shield temperature was being adjusted which caused a delay in actually stabilizing the insulation temperature. However,



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the vapor-cooled shield temperature was controlled easily within a tolerance of $\pm 20^{\circ}\text{F}$ during the rapid cooling but should have been controlled to a slower rate of cooling to maintain the proper boiler shield temperature. A rapid rate of cooling was desirable since the planned test time with hydrogen was limited for obtaining stabilized results.

Immediately before introducing helium into OTTA the tank and insulation system was precooled with liquid hydrogen. Several evacuation and helium gas purge cycles were performed to remove the residual hydrogen gas before the actual helium fill. Liquid helium was then introduced into OTTA with a minimum loss due to cooldown. The tank was actually overfilled with respect to the pressure level being maintained which caused a discharge of liquid out of the venting system for a period of time. When the pressure was finally adjusted to match the specific volume that would just fill the tank, stabilization was achieved within 48 hours.

Time presented the opportunity in this project to experience a significant observation of the effect of no-loss storage during the nitrogen and helium exposure. When outflow was stopped while the tank contained liquid nitrogen an irregular pattern of pressure rise and fall occurred. The pressure rose rapidly to a rather high level then dropped off rapidly to a new low level then returned to a new high level. This sequence was repeated several times. The general trend of the pressure rise would indicate a heat leak rate of approximately 19 Btu/hr. This cycle of pressure rise and fall continued throughout the observation period. The pressure level was always below critical for the nitrogen test. When flow was stopped while the tank contained helium the pressure rose at a constant rate through both the saturation and overcritical ranges without the previously observed cycling effect. At the time of the helium test the tank was approximately 43% full which may have had some stabilizing effect on the results in combination with the very low critical pressure.

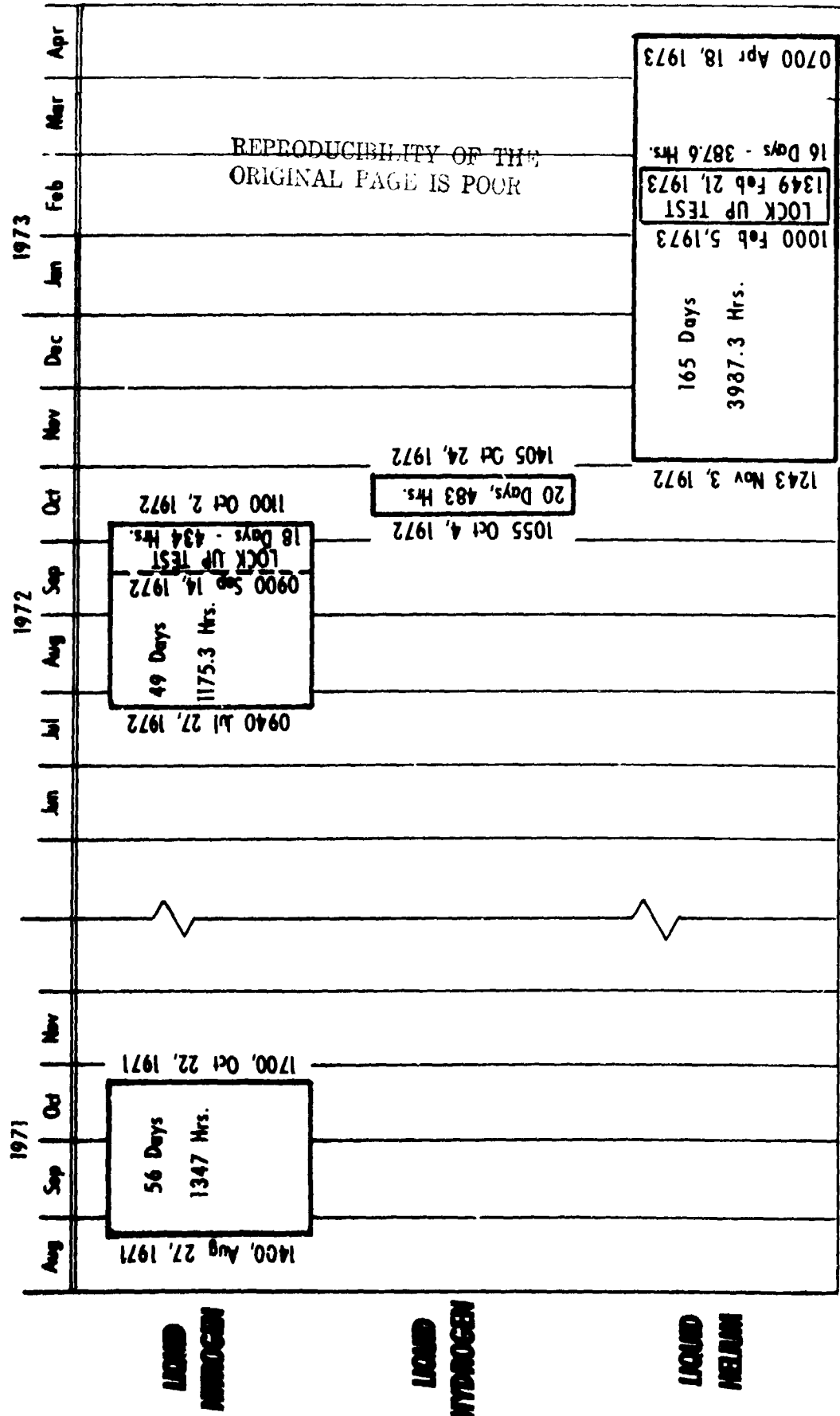
Numerical estimates and actual results of testing are compared in Table 5. The chronological test sequence is displayed in Figure 17.



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Figure 17

OTT A

CRYOGEN TEST RECORD





10.0 OBSERVATIONS, CONCLUSIONS, AND RECOMMENDATIONS

10.1 Insulation System Cooling for Optimum Performance

The function of a cryogenic container insulation system is to protect the cryogen from absorbing heat. To perform this function in an optimum way, each element of the system must reach the proper temperature to provide a thermal balance. The time required to reach a thermal balance is the "stabilization time".

Stabilization of multilayer insulation systems, such as OTTA, requires steady state (temperature, pressure, flow) operation for considerable periods of time (14 to 21 days for initial cooldown -- reference Figures 18, 19, 21, and 22). The shortest stabilization time can be provided by proper flow control in the vapor cooling system (reference Figure 21). However, to control the flow to produce the proper temperature adjustment requires some prior knowledge of the right temperature level to be attained. Otherwise subcooling may occur in the shields which will require additional stabilization time. (Very slow recovery -- reference Figures 21 and 23.)

Good multilayer vapor-cooled insulation systems respond very slowly to changes in operating conditions. Therefore, to produce the best results for storage of cryogens, violent changes in pressure and flow rate should be avoided.

In testing a system such as OTTA where time to reach steady test conditions may be of some concern, control of the vapor cooling flow should be imposed during filling of the tank while observing the shield temperatures. By manipulating the flow properly, the shields will reach the operating temperature in the shortest possible time.

When storage of cryogens is the primary concern, the vapor cooling system should be left open during the filling operation to drop the shield temperatures to the lowest possible level before the tank is full. This will provide extended storage time for constant pressure operation.

10.2 Correlation of Results with Analytical Predictions

Table 5 shows the proposed values of heat leak and the results of testing. It can easily be seen that predictions were conservative. Prior to and during the contract period the thermal effectiveness of the OTTA system was continuously examined analytically. As improved technical information and definite manufacturing details could be incorporated into the computer program the predicted value of thermal effectiveness was refined. Results of testing show that the actual thermal effectiveness was better than predicted and that the accuracy of predictions was improving.

A Beech Aircraft Corporation funded program of investigation into insulation evaluation provided first-hand knowledge of the probable effectiveness of



the actual insulation layup. The actual layup was simulated in the Beech comparator and tested using liquid nitrogen as the cryogen.

During the OTTA testing it was observed that multilayer insulation is very sensitive to vacuum level. This fact was dramatically brought out in the results of the two nitrogen tests. Comparison of 1971 test performance when the vacuum level was dynamically maintained at approximately 5×10^{-5} mmHg, and the 1972 test performance with the static vacuum level at 2×10^{-7} mmHg show clearly the system sensitivity to vacuum pressure level, since this parameter is the primary difference in the two test sequences.

Accurate predictions of thermal effectiveness for complex systems such as OTTA depend on many variables. The conduction coefficients for materials, reflectance of radiation barriers, the density of insulation, vapor flow rate, vacuum level, cryogen under consideration, pressure of the cryogen, and the consistency of environmental temperature must be precisely controlled and evaluated for thermal effects if predictions are to be accurate. Even though much work has been done in the evaluation of materials, the coefficients and the equations are very seldom absolute. A major contribution to the accuracy of thermal predictions is involved with judgement and experience of the investigator in considering the coefficients, thermal equations, and particular system heat balance. Generally, predictions will be conservative because of the variable nature of coefficients with respect to temperature and the need for finite values in the analytical solutions. Investigators tend to be conservative in assigning values of coefficients so that their predictions will be safely in a range where there is a good probability of the actual results being better.

Beech predictions proved to be conservative as expected but our continuous analytical investigation during the project showed that meticulous attention to actual detailed construction and using development information, as available for thermal effectiveness of the radiation barriers would provide continuously more accurate estimation of the thermal effectiveness of the OTTA system. Now, after having experienced the testing of the system, much more precise predictions can be made for future similar systems of thermal protection.

10.3 Constant Pressure Operation without Flow in the Vapor-Cooled Shield

Best thermal effectiveness in a system like OTTA occurs when the tank is maintained at a constant pressure with the boil-off gas being discharged through the vapor-cooled shield flow channel. However, considerable interest was generated during the program relative to performance without vapor-cooled shield operation. Therefore, a test was performed during helium exposure to examine the effect of bypassing the vapor-cooled shield with the discharging boil-off gas. The results showed a drastic reduction in thermal effectiveness when steady state heat leak rose 8.6 times the minimum rate.



10.4 Stratification Effects

Figures 20 and 23 show pressure variations that occurred when the out-flow of vapor was stopped from OTTA. Prior to September 20, 1972, no real indication had been observed that stratification might have any effect on the observed results. Late in the day on September 20th, after six days of "no-loss" storage, the steady rise of tank pressure stopped and sharply decreased for no apparent external reason. For the next 12 days pressure in the OTTA rose and fell in an irregular pattern but showed a steady trend to increasing pressure.

Instrumentation was not provided to measure the temperature at different depths in the tank and the sensors on top and bottom of the pressure vessel indicated the same temperature. If there was actually a temperature difference between top and bottom of the tank the platinum sensors did not detect it even at the time of rapidly changing pressure.

Personnel at the National Bureau of Standards (NBS) advanced the theory that the warmer fluid is in the stratified layers at the bottom of the tank and periodically develop a gas bubble. The bubble rises through the stratified layers of fluid enlarging as it approaches the vapor/liquid interface and then bursts into the ullage space causing a minor amount of atomization of fluid which lowers the temperature of the vapor causing the observed pressure to drop.

The maximum fluctuation in pressure from high to low was no more than 2.0 psi at any time, which would not have been detected on the pressure gauges supplied with the unit.

The construction of OTTA may have contributed to the observed condition which may or may not be a product of stratification. The fill line extends without a gas trap from the bottom of the pressure vessel to the girth ring, which allows fluid to move up the line toward the warmer area to a point where the pressure is balanced. With the fluid in the pipe close to the outside surface, pressure could rise in the line to force the fluid down toward entrance to the pressure vessel. A gas bubble would then be discharged into the tank. Depending on the size of the gas bubble developed the pressure in the fill line would be reduced again allowing the fluid to rise in the fill line and start the percolation process all over. If this were the case, stratification would not play an important role in the observed effects. It is suspected that this phenomena is more likely to occur when the tank is full of liquid than when at lower levels.

10.5 Computer Design

The thermal protection system for OTTA was designed through repeated improvement of computer models. As refined values of conduction and radiation coefficients were available and as details of the mechanical design were available they were input to the computer model. The solution



determined from the computer model requires many complex and iterative calculations which would be impractical from a time and accuracy standpoint by any other means. With a computer model using tested materials, it is conceivable that very accurate thermal systems (MLI) can be designed with confidence for specific applications.

10.6 Silvered Mylar and Silk

Pure silver, as used in coating mylar, is subject to rapid degradation of surface brightness due to tarnishing from atmospheric oxidation.

Silk material, being a cellular animal product caused much apprehension because of the probability of outgassing.

In practice, Beech found that tarnishing of silver and outgassing of silk were controllable and acceptable respectively.

Examination of tarnished silver on mylar was made to determine degradation of the emissivity value. The results of these tests were only qualitative rather than statistical since the tarnishing environment was uncontrolled. "Mild" tarnishing was found to cause relatively little degradation in reflective quality (10% loss) while "heavy" tarnishing caused the reflectance to degrade by a factor of up to two. The "heavy" tarnishing effect is sufficiently degrading to cause elimination of silvered mylar from economical use because the emissivity would be the same or worse than less expensive material not subject to tarnishing. However, control of the tarnishing of silver was found to be practical and feasible within the state-of-the-art of clean environments as provided in normal space hardware manufacturing.

The outgassing characteristics of the silk material are still in a nebulous state of determination. Practical outgassing tests are very difficult to perform and require a high degree of sophistication to produce meaningful data. Beech elected to use silk on the strength of practical application tests performed to determine the difficulty in producing the required vacuum level prior to OTTA manufacture. At this time, after over 18 months of vacuum exposure, it is Beech's observation that silk spacer material does not significantly deteriorate in a vacuum environment and that satisfactory (10^{-6} to 10^{-8} mmHg) vacuum levels can be maintained while using silk.

10.7 Weighing System

A BLH Electronics, Inc. load cell system was installed to determine the quantity of cryogen contained by OTTA. During the extended test period it was found that this weighing system was highly sensitive to the temperature environment. A deviation of only a few degrees of temperature was sufficient to cause a noticeable change in the observed weight reading. The temperature effect on the weight reading was consistent regardless of the total weight being read.



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The maximum weight variation observed for one degree of temperature variation was 4.0 pounds.

The conclusion to be drawn from the observed data with respect to the weighing system is that absolute readings can only be considered accurate to within 5 pounds if the temperature variation is held to one degree Fahrenheit. Considering the OTTA tare weight alone (4595 pounds) the maximum weight variation due to one degree temperature change represents only 0.1 percent error.

Using a reference temperature (75°F) for the base-line weight reading, a plus deviation in chamber temperature produces a lesser weight reading. A minus deviation in chamber temperature produces a greater weight reading.



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Table 5. OTTA PERFORMANCE

PROPOSED TO NASA	LO ₂	LN	LN ₂	LHe
Heat Leak Btu/hr	21.63	10.9	21.09	
Flow Rate \dot{m} lb/hr	0.236	0.056	0.246	
Heat Flux Btu/hr-ft ²	0.1082	0.0545	0.1055	
% Boil-off per Day	0.035	0.136	0.052	
PROPOSAL REVISION TO BAC PREDICTION (from Thermal Research after proposal)				
Heat Leak Btu/hr	17.58	5.08	16.08	
Flow Rate \dot{m} lb/hr	0.192	0.026	0.188	
Heat Flux Btu/hr-ft ²	0.088	0.025	0.080	
% Boil-off per Day	0.029	0.063	0.039	
TEST RESULTS (1st Test Run) Sep - Oct 1971				
Heat Leak Btu/hr			13.095	
Flow Rate \dot{m} Btu/hr-ft ²			0.152	
Heat Flux Btu/hr-ft ²			0.066	
% Boil-off per Day			0.032	
TEST RESULTS Aug 72 - Jan 73				
Heat Leak Btu/hr		4.45	8.40	1.22
Flow Rate \dot{m} lb/hr		0.0227	0.1006	0.1500
Heat Flux Btu/hr-ft ²		0.0223	0.0420	0.0061
% Boil-off per Day		0.0560	0.0220	0.2100



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G L O S S A R Y

BS	boiler shield
$^{\circ}\text{F}$	degrees Fahrenheit
ft	feet
F_{tu}	ultimate tensile stress
F_{ty}	yield tensile stress
g	acceleration of gravity
H_L	enthalpy of the liquid
H_v	enthalpy of the vapor
in.	inches
lb.	pounds
lbm	pound mass
LH_2	liquid hydrogen
LHe	liquid helium
LN_2	liquid nitrogen
LO_2	liquid oxygen
M_1	moment at point 1
M.S.	margin of safety
\dot{m}	mass flow rate in lb/hr
mmHg	millimeters of mercury
n_x, N_x	g acceleration in the X axis
OMS	Orbital Maneuvering System
PV	pressure vessel
psi	pounds per square inch
psia	pounds per square inch absolute
q	rate of heat transfer Btu/hr
sec	second
S.F.	safety factor
t	thickness
T	tensile force
TS	temperature sensor
V	shear force
VCS	vapor-cooled shield



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GLOSSARY (contd)

ϵ	emissivity
ϵ_{eff}	total effective blanket emittance
θ_L	heat required to expell one pound of liquid at constant pressure
θ_v	heat required to expell one pound of vapor at constant pressure
ρ	density lb/ft ³



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APPENDIX A

D R A W I N G S

Gage Assembly - Ion	460947
General Arrangement	460966A
Schematic	460992
Temperature Sensor Installation	660943
Support Installation	660969
Module - Control	660995
Organization of Drawings	Table 2

173 DIA 3 HOLES
200
TO MATCH 660968-11

1.75
1.06
1.88
0.60 ± .005
0.62 ± .005
0.6R
8.8 ± .003 DIA
1.50 DIA BC
.020 P TYP
2 PLACES
SECTION A-A
DETAIL - 3

SECTION A-A

DETAIL-3

454-5075 TYP
2 PLACES

SEE DETAIL

453-5014

SCREW/C
MS21042L4
TYP 6 PLACES

-274-003

5 THE BI-METAL TUBE TEMPERATURE IN THIS AREA SHALL NOT EXCEED 800°F

NOTES:

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FOLDOUT FRAME 2

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ORIGINAL PAGE IS POOR

AS REQD	WELD WIRE	QQ-R-566 CL 4043	AL WELD WIRE
AS REQD	WELD WIRE	MIL-R-5031 ER347 CL7A	CRES WELD WIRE
AS REQD	WELD WIRE	VIL-E 21562 RH 82	NCO 82 WELD WIRE
1	CREW	99313	
2	FLANGE - ROTATABLE - CONFLAT	99313	954-5075
1	WASKET-FLANGE	99313	953-5014
1	TUBE ION GUAGE	15691	274-003
6	NUT- SELF-LOCKING		MS21042L4
1	TUBE	-9	WW-T-7006 TEMPER T6 1.00D x .065W TUBE x 2.2 6061-T6 AL ALLOY
1	TUBE	-7	WW-T-7006 TEMPER T6 1.00D x .065W TUBE x 2.2 6061-T6 AL ALLOY
1	JOINT-TRANSITION, BI-METAL	-5	
1	ADAPTER	-3	QQ-S-573 2.0 DIA COMP 304 BAR x 1.8 LG 304 CRES
1	ASSY	-1	
-1	QTY REQD	SYM	NOMENCLATURE OR DESCRIPTION
			CODE IDENT
			PART OR IDENTIFYING NO
			DASH NO
			SPECIFICATION
			MATERIAL OR NOTE
			UNIT WT
			ZONE
			ITEM NO

IDENT AND QTY REQD FOR TAB DASH NO ITEMS				LIST OF MATERIALS OR PARTS LIST							
STANDARD PRACTICE NOTES SEE BENCH STANDARD DRAWING NO 130430 MATERIAL & OR PROCESS				CONF NO BE <i>R. S. Sayre</i> 10-1-70 BY <i>S. Smith</i> 10-1-70 IN CH <i>A. J. Smith</i> 10-1-70 CHECK REVISION RELIABILITY BENCH APP <i>C. J. Smith</i> 10-1-70 CUSTOMER APP				Beech Aircraft Corporation BOULDER DIVISION, BOULDER, COLORADO GAGE ASSY - ION D 07399 460947 SCALE 1/1 SHEET			

1-1 660960 S.C.

DATE 10-1-70

BY *R. S. Sayre*

IN CH *A. J. Smith*

CHECK *C. J. Smith*

REVISION

RELIABILITY

BENCH APP

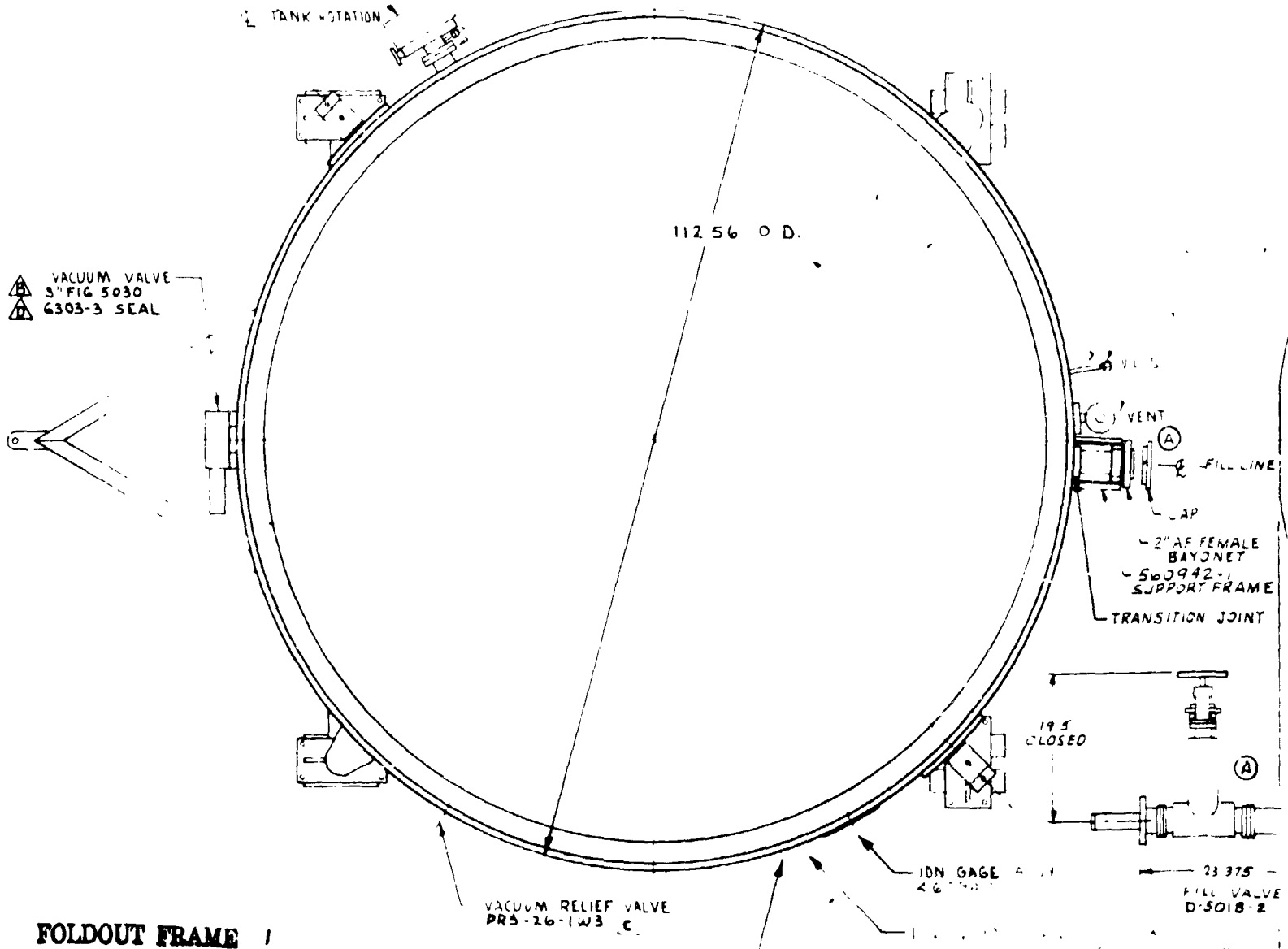
CUSTOMER APP

60947

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TANK NOTATION



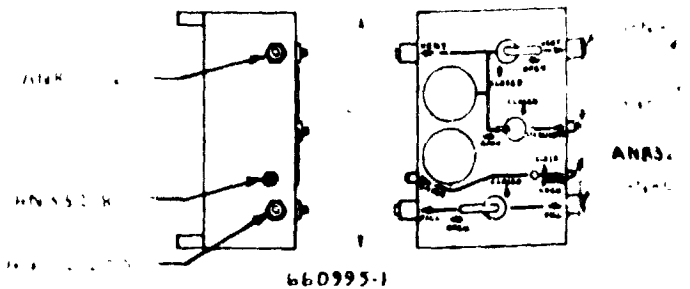
- △ PART NO. OF CONSOLIDATED PRECISION CORP - RIVIERA BEACH, FLA (A)
- △ PART NO. OF VARIAN - LOS ALTOS, CALIF.
- △ PART NO. OF PARKER SEAL CO. - ENGLEWOOD, COLO.
- △ PART NO. OF CRYOLAB - LOS OSOS, CALIF.
- △ PART NO. OF TEMESCAL METALLURGICAL CORP - BERKELEY, CALIF.
- △ PART NO. OF DEUTSCH CO. - BANNING, CALIF.

3 FOR FLOW SCHEMATIC SEE 460992 DRAWING.

2. ALL SURFACES EXPOSED TO LIQUID OXYGEN SHALL BE CLEAN PER THE REQ. OF BELLM SPEC B.S. 13779.

1. ALL SURFACES EXPOSED TO VACUUM SHALL BE CLEAN PER THE REQ. OF BELLM SPEC B.S. 13879.

NOTES:



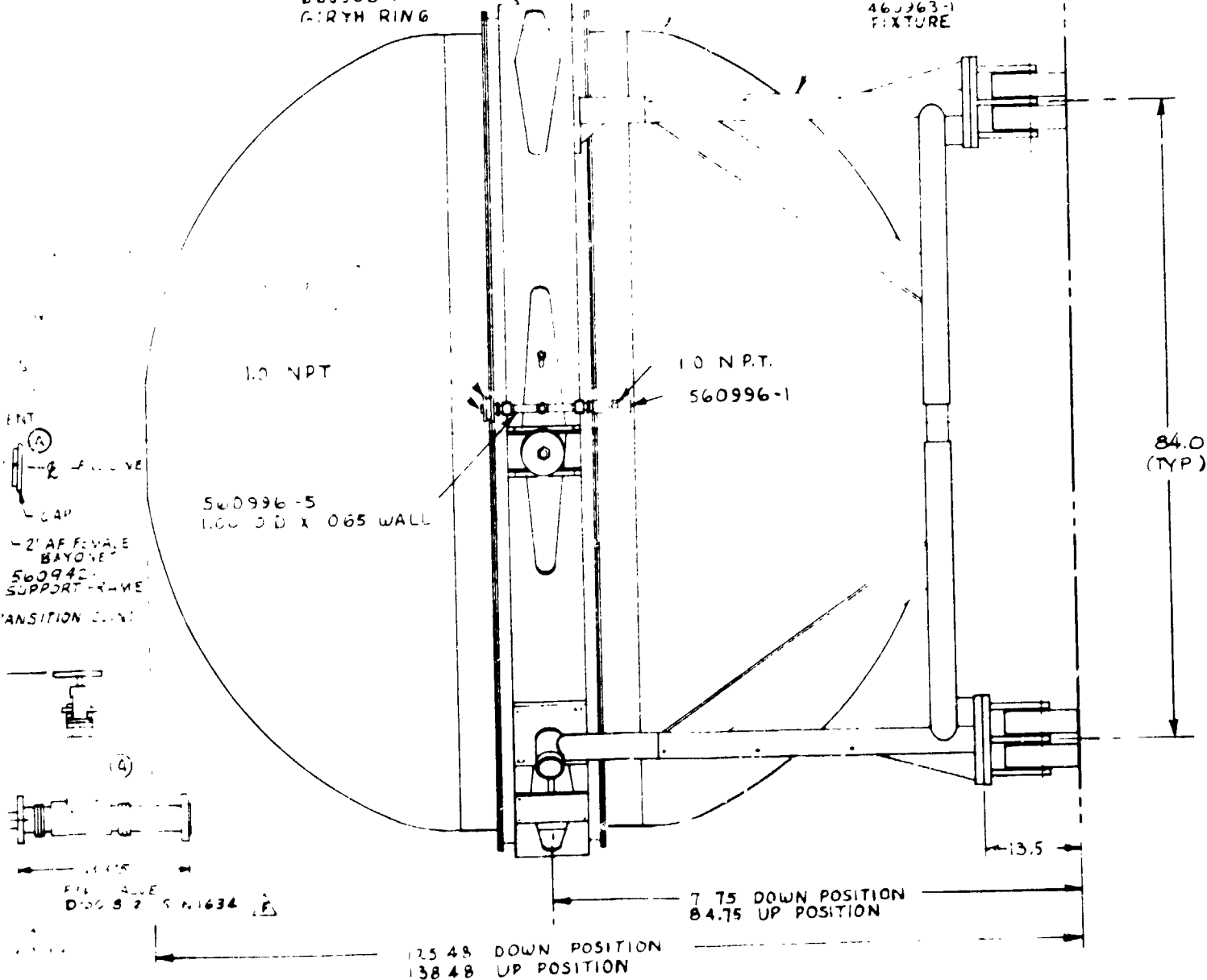
FOLDOUT FRAME 2

REV. NO.		DATE	APPROVED
1	A	12-73	H. CHRONIC
DESCRIPTION		REMOVED PIPE AND AN 818-203 F. TING ADDED 2" VAL JAC BAYONET SUPPORT 560992 VAL JAC VALVE D 5018-2	

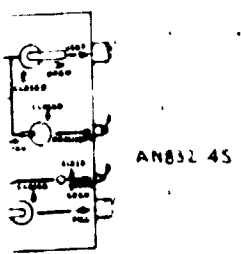
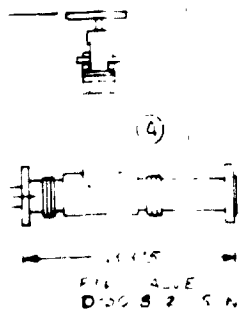
461045-1
HEAD ASSY

660967-1
INSULATION INSTL
660968-1
GIRTH RING

460963-1
FIXTURE



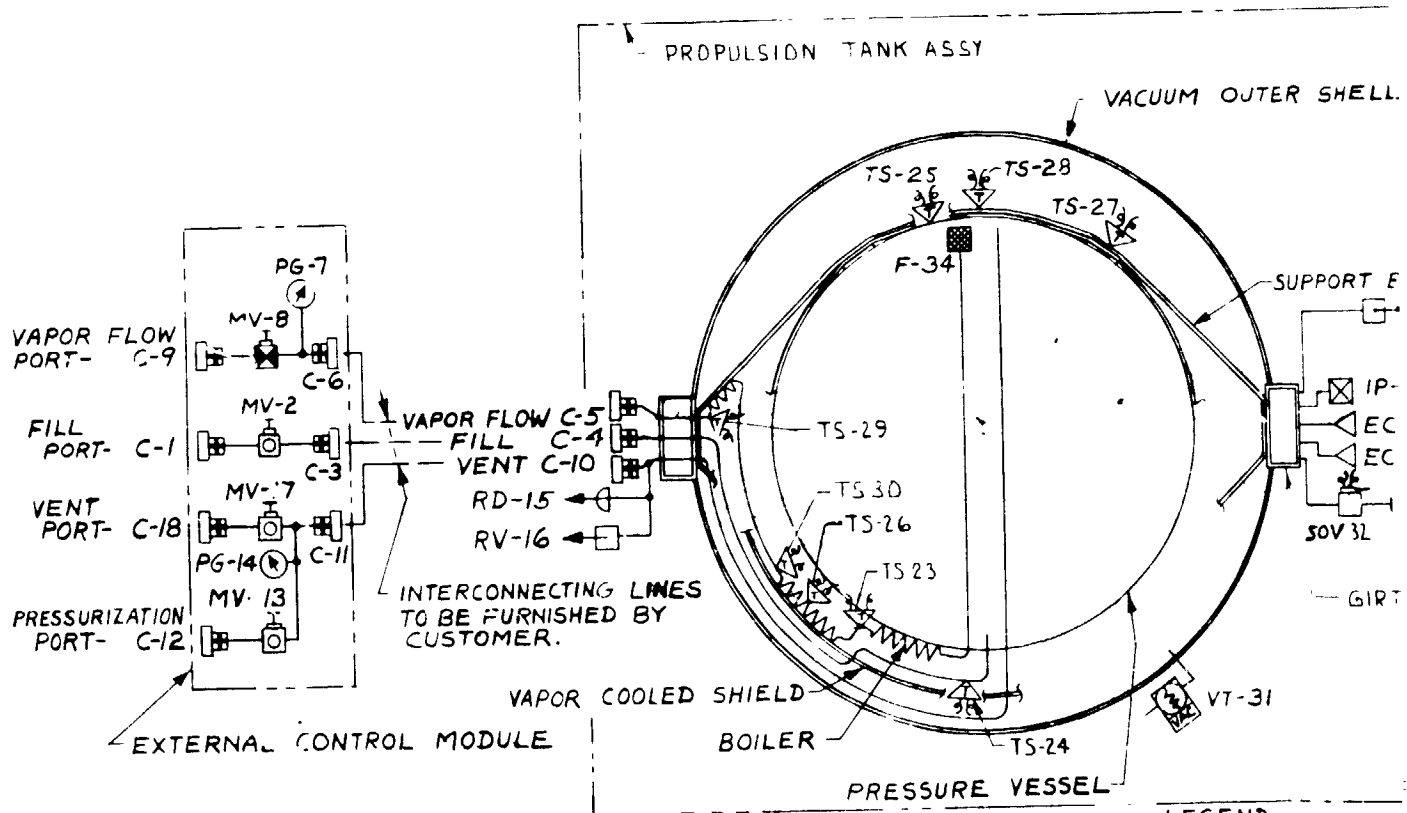
ENT
2" VALVE
CAP
2" AFF VALVE
BAYONET
560942
SUPPORT FRAME
TRANSITION CLAMP



QTY		SYM	DESCRIPTION	CORE	PART OR IDENTIFYING NO	BATCH NO	SPECIFICATION	MATERIAL OR NOTE	UNIT	REQD	ISSD
1			INSUL INSTL		660967-1						
1			TRANS FIXTURE		460963-1						
1			MODULE CONTROL		660995-1						
1			GENERAL ARRANGEMENT								
LIST OF MATERIALS OR PARTS											
STANDARD PRACTICES REFER TO SEE DESCH STANDARD DRAWING NO 130430 MATERIAL & QTY REQUIRED			DATE 6-7-71			Beech Aircraft Corporation BOULDER DIVISION, BOULDER, COLORADO					
DATE 6-7-71			DATE 6-7-71			GENERAL ARRANGEMENT-NASA PROPULSION TANK OTTA					
DATE 6-10-71			DATE 6-10-71			D 07399 460966 A					
DATE 6-10-71			DATE 6-10-71			SCALE 1/10					

460966 A

OTTA FLUID FLOW SCHEMATIC



1. SYMBOLS ARE PER NASA
STANDARD MSFC-STD-162A

NOTE:

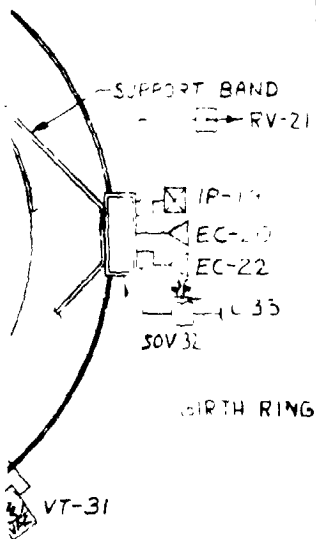
LEGEND	
C	COUPLING
F	FILTER
EC	ELECTRICAL CONNECTOR
MV	MANUAL VALVE
PG	PRESSURE GAGE
RD	RUPTURE DISC
RV	RELIEF VALVE
TS	TEMPERATURE SENSOR
VT	VACUUM TRANSDUCER
IP	ION PUMP-VACUUM
SOV	SHUT OFF VALVE (ELECTRO PNEUMATIC)

FOLDOUT FRAME /

REVISIONS				
ZONE	LTE	DESCRIPTION	DATE	APPROVED

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

IM OUTER SHELL



LEGEND

PLING
ER
CTRICAL CONNECTOR
UAL VALVE
SSURE GAGE
TURE DISC
EF VALVE
PERATURE SENSOR
JUM TRANSDUCER
PUMP-VACUUM
T OFF VALVE
(CTRO PNEUMATIC)

FOLDOUT FRAME 2

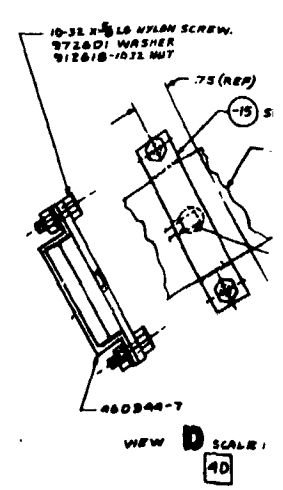
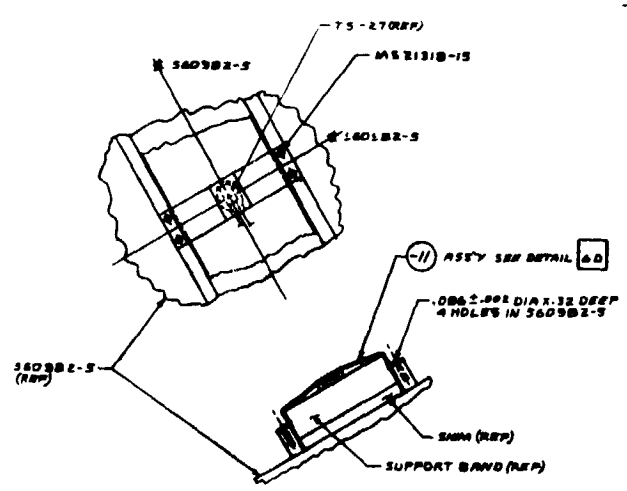
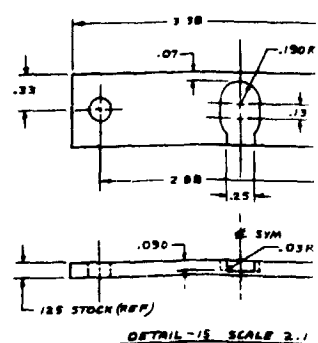
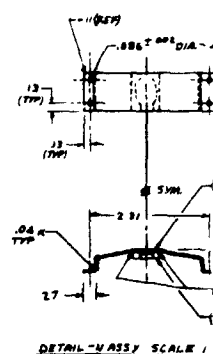
STANDARD PRACTICE NOTES SEE BENCH STANDARD DRAWING NO. 130430 MATERIAL &/OR PROCESS			CONV NO 9-24-70		Beech Aircraft Corporation BOULDER DIVISION, BOULDER, COLORADO	
			3-17-71		FLUID FLOW SCHEMATIC- PROPULSION TANK, NASA CRYO	
			3-22-71		D 07399 460992	
			3-23-71		SCALE NONE	
CHY BBS 100 1720	USED ON MEET ART	ACORD				

460992

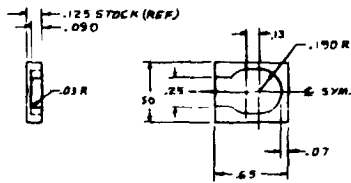
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7

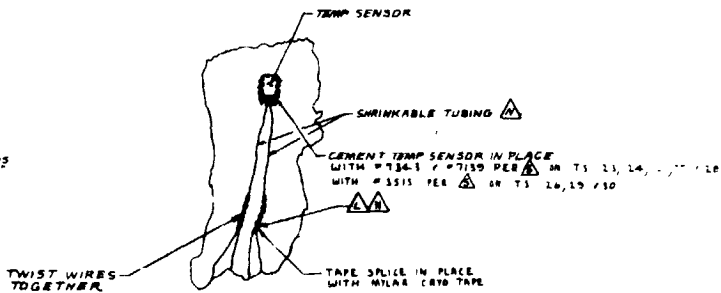
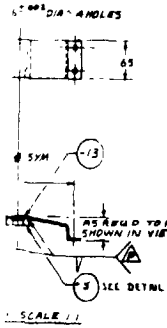
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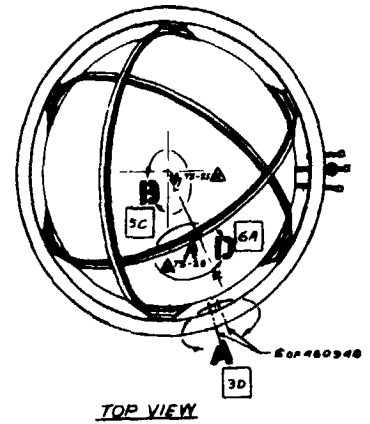
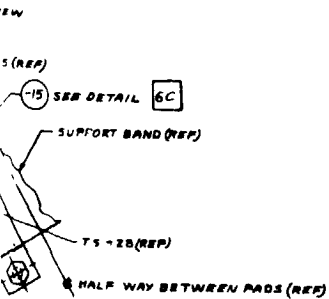
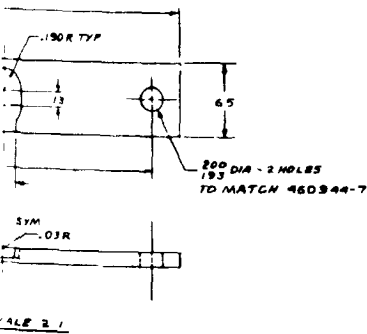
FOLDOUT FRAME



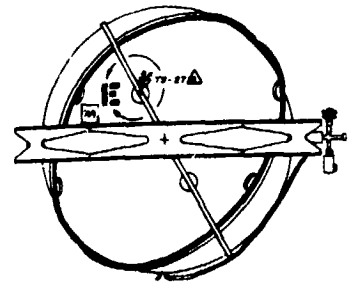
DETAIL - 3 SCALE 2:1



VIEW B SCALE 1:1 (TYP FOR ALL TEMP SENSORS)



TOP VIEW



SIDE VIEW

2. REMOVE ALL BURRS & BREAK SHARP CORNERS APPROX .015.
3. ALL SURFACES EXPOSED TO VACUUM SHALL BE CLEAN PER BOUGH SPEC D.S. 1379.

FOLDOUT FRAME 2

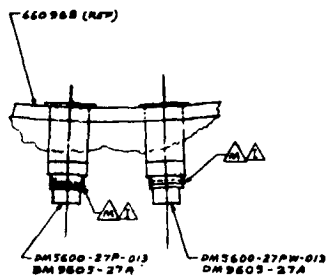
NOTES:

660543

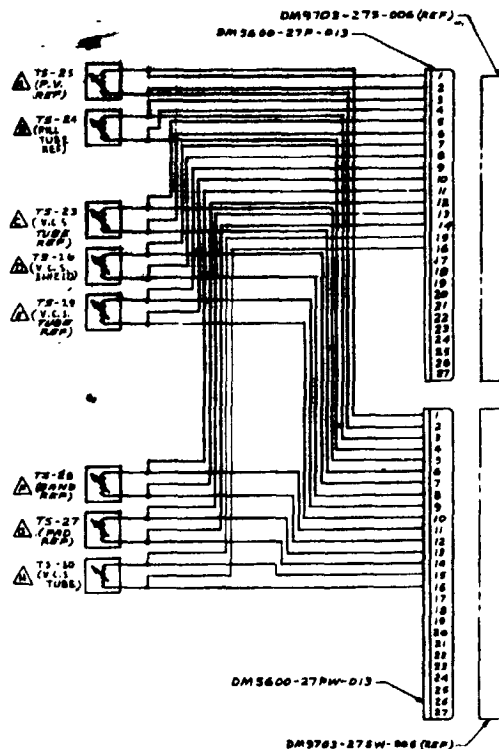
3

2

1



VIEW
SCALE 1/4" = 1"



TEMPERATURE SENSOR SCHEMATIC

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

FOLDOUT FRAME 3

- ▲ MAY BE PURCHASED FROM COST PRODUCTS - SANTA, CALIF 91705
- ▲ OMITTED
- ▲ PREPARE SURFACES & APPLY ADHESIVE PER INSTRUCTIONS PROVIDED BY MANUFACTURER. CURE CEMENT AT 140° F FOR 2 HOURS USING A HEAT LAMP.
- ▲ P/N GRIES REPRODUCER CO. NEW ROCHELLE, N.Y.
- ▲ INSERT GAS ARC WELD PER DEECH SPEC D.S. 510 EXCEPT Omit THE REST RADIOGRAPHIC & FLUORESCENT PENETRANT INSPECTION. USE ELECTRODES PER RD-R-366 TYPE 4043.
- ▲ USE AS REFER TO INSULATE ALL ELECTRICAL LEADS & JOINTS WITH SHOWN TAPPING BY APPLYING HEAT AT A MAX OF 180° F.
- ▲ BOND IN BLUE CANN WITH #7143 (1" DIA. PCL)
- ▲ SOLDER ALL ELECTRICAL WIRES PER MH-S-6072. USE MATERIAL FOR 60-40 SN/60 WRP.3. CLEAN OFF ALL RESIDUAL FLUX IMMEDIATELY AFTER SOLDERING.
- ▲ MAY BE PURCHASED FROM: ROSEMOUNT ENGINEERING CO. 4900 WEST 78TH ST, MINNEAPOLIS, MINNESOTA, 55424.
- ▲ PART NO OF DEUTSCH CO BANNING, CALIF.
- ▲ VACUUM LEAK CHECK. MAX ALLOWABLE LEAK RATE 1 x 10⁻⁵ ATG CC/SEC.
- ▲ ATTACH TEMP SENSOR NO. 38 (SN L 174) IN V.C.L. TUBE 6.5 FROM SOUTH POLE (V.C.L. END)
- ▲ ATTACH TEMP SENSOR NO. 27 (SN 261) ON THE SUPPORT BAND 5.5 IN & 6 IN (S.S. 10) ATTACH TO THE PAD NEAREST THE ELECTRICAL CONNECTOR.
- ▲ ATTACH TEMP SENSOR NO. 28 (SN 261) ON THE SUPPORT BAND 5.5 IN, IN THE NORTHERN HEMISPHERE, 1.75 IN FROM S RAIL CURV GOING TO THE S RAIL.
- ▲ ATTACH TEMP SENSOR NO. 19 (SN 1170) ON THE V.C.L. TUBE NEXT TO S RAIL GOING TO THE S RAIL TUBE OUTLET.
- ▲ ATTACH TEMP SENSOR NO. 10 (SN 1170) ON THE V.C.L. TUBE NEXT TO S RAIL GOING TO THE S RAIL TUBE OUTLET.
- ▲ ATTACH TEMP SENSOR NO. 27 (SN 261) ON THE S RAIL TUBE 1.5 IN FROM SOUTH POLE (S RAIL END).
- ▲ ATTACH TEMP SENSOR NO. 16 (SN 1170) ON THE V.C.L. TUBE OUTSIDE OF SHIELD SHIELD (OUTSIDE OF SHIELD).
- ▲ ATTACH TEMP SENSOR NO. 10 (SN 1170) AT NORTH POLE OF PRESSURE SENSOR IN LINE NO. 2.

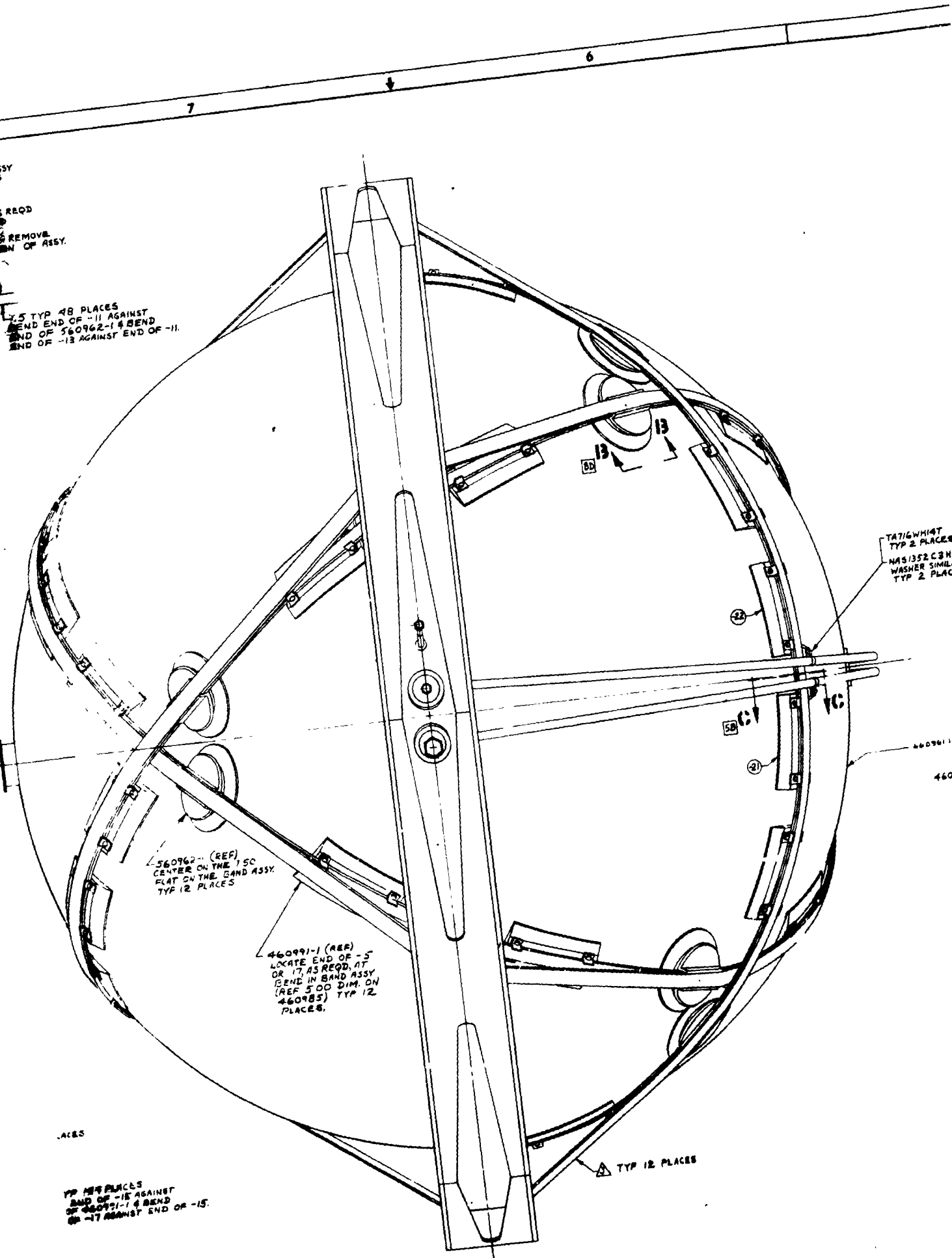
NOTES:

QTY	DESCRIPTION	REF	QTY	DESCRIPTION	REF
2	WIRE BUNDLE TIES		1	NYLON	GEN
2	FLAT WASHER	972601	1	NYLON	6A
2	NUT (M-32)	972618	1	NYLON	6A
2	NEW BOND SCREW		1	NYLON	6A
1	CLAMP	460344-7	1	NYLON	6A
1	STRAP		1	NYLON	6A
1	STRAP		1	NYLON	6A
1	ASSY		1	NYLON	6A
1	ACCELERATOR	EC 3515	1	NYLON	6A
1	BASE	EC 3515	1	NYLON	6A
1	COVER		1	NYLON	6A
4	DRIVE SCREW	M82318-12	1	NYLON	6A
1	WELD WIRE		1	NYLON	6A
1	HEAT SHRINKABLE TUBING		1	NYLON	6A
1	RESIN	#7143	1	NYLON	6A
1	CATALYST	#7143	1	NYLON	6A
1	PROTECTIVE CAP	DM5605-27A	1	NYLON	6A
1	ELECTRICAL RECEPTACLE	DM5600-27PW-013	1	NYLON	6A
1	ELECTRICAL RECEPTACLE	DM5600-27P-013	1	NYLON	6A
1	TEMPERATURE SENSOR		1	NYLON	6A
1	SOLDER		1	NYLON	6A
1	CRYO TUBE		1	NYLON	6A
1	ELECTRIC WIRE		1	NYLON	6A
1	INSTALLATION		1	NYLON	6A

<p>SENSOR-TEMPERATURE INSTALLATION</p> <p>660999 660943</p>		<p>Good Aircraft Corporation</p> <p>10000 10000</p>
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SSY
REQD
REMOVE
OF ASSY.

7.5 TYP 48 PLACES
END OF -11 AGAINST
END OF 560962-1 & BEND
END OF -13 AGAINST END OF -11.



TATIGWHIST
TYP 2 PLACES
WAS 1352 C3H8
WASHER SIMILAR TO ANY
TYP 2 PLACES

1.0
(RE)

460991-1 (REF)

SEC
S
BAND
NOT

560962-1 (REF)
CENTER ON THE 150
FLAT ON THE BAND ASSY.
TYP 12 PLACES

460991-1 (REF)
LOCATE END OF -5
OR 17, AS REQD, AT
BEND IN BAND ASSY
(REF 5.00 DIM. ON
460985) TYP 12
PLACES.

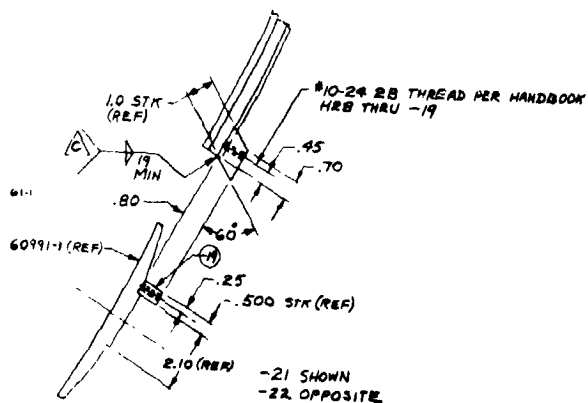
ACES

TYP 12 PLACES
BAND OF -15 AGAINST
END OF 460991-1 & BEND
ON -17 AGAINST END OF -15.

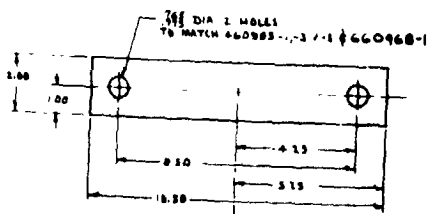
TYP 12 PLACES


FOR NOT FRAME

WH14T
PLACES
5263H8
R SIMILAR TO AN935-10
2 PLACES



SECTION (C-C) [68]
SCALE: $\frac{1}{2}$
BAND ASSY. TUBE, ATTACHING HDWE.
NOT SHOWN FOR CLARITY



DETAIL -3, -5, -7 1-9 
SCALE: $\frac{1}{2}$

1. ALL SURFACES EXPOSED TO VACUUM SHALL BE CLEAN PER THE REQ OF TECH SPEC BS 11879.
2. REMOVE ALL BURRS AND BREAK SHARP CORNERS APPROX 0.01.
3. 100% FINISH ALL OVER

FOLDOUT FRAME 2

- ⚠ BAND ASSY TENSION HERE SHALL BE 3000 ± 100 LBS.
- ⚠ THE TOTAL SHIM THICKNESS BETWEEN THE BAND ASSY & SHOE SHALL BE THE SAME ON EACH PAD ON EACH BAND ASSY. THE TOTAL SHIM THICKNESS MAY VARY FROM ONE BAND ASSY TO THE NEXT.
- ⚠ THE TOTAL SHIM THICKNESS BETWEEN THE BAND ASSY & PAD SHALL BE THE SAME ON EACH PAD ON EACH BAND ASSY. THE TOTAL SHIM THICKNESS MAY VARY FROM ONE BAND ASSY TO THE NEXT.
- ⚠ WITH NO WASHER ON BOLT, THREAD BOLT IN UNTIL BOLT END BOTTOMS AGAINST ONE OF THE THREE HOLES IN GEAR. RUN BOLT IN UNTIL HEAD BOTTOMS AGAINST -9. IF BOLT END BOTTOMS, STAY ON TO BOLT END AND -9. IF BOLT HEADS TO THIS STUCK AND INSTALL STAIN ON BOLT. IF BOLT HEADS BOTTOMS, INSTALL ONE WASHER BOLT.
- ⚠ TEMPERATURE OF SP-RITE JUMP IN HOTSPOT AREA SHALL NOT EXCEED 50.
- ⚠ LEAK CHECK WELD - MAX LEAK RATE IS 1.0" SP/CC SEC HELIUM GAS.
- ⚠ INSPECTION WELD PER CHECK SPEC. B-8-800 EXCEPT ON THE PER 5. RADIOGRAPHIC INSPECTION & FLUORESCENT DETECTANT INSPECTION (PER 2.0. USE WELD WELD PER B-8-800 (1.0-800).
- ⚠ TIGHTEN BOLTS TO JUST TAKE UP CLEARANCE WITHIN EACH STACK OF PARTS WHEN BOLTS CLAMP.
- ⚠ USE AN BEER OF THE -8.8 AND -9 TO FILL UP THE GAP BETWEEN THE BAND ASSY AND THE SHOE. RUN ALL THE SAME AMOUNT OF THE BEER 3000 LBS. IN EACH END OF EACH BAND. IF THE BEER IS USED HERE USING THE THICKEST PAST POSSIBLE RATHER THAN SEVERAL THIN PASTS.

NOTE 5:

660969

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

FOLDOUT FRAME 8

WEIGHT SHALL BE 3000 ± 100 LBS.

THICKNESS BETWEEN THE BAND ASSY & SHOE SHALL
EACH SHOE ON EACH BAND ASSY. THE TOTAL
MAY VARY FROM ONE BAND ASSY TO THE NEXT.

THICKNESS BETWEEN THE BAND ASSY & PAD
ON EACH PAD ON EACH BAND ASSY. THE TOTAL
MAY VARY FROM ONE BAND ASSY TO THE NEXT.

IN BOLT, THREAD BOLT IN UNTIL BOLT END BOTTOMS
REACHED. HOLD IN GIRTH RING ASSY OR UNTIL BOLT
RING - 7. IF BOLT END BOTTOMS, STACK UP THE WAS-
-1216 WASHERS WHICH CAN BE INSTALLED BETWEEN THE
ADD ONE WASHER TO THIS STACK AND INSTALL TOTAL
IF BOLT HEAD BOTTOMS, INSTALL ONE WASHER ON

METAL JOINT IN NOTED AREA SHALL NOT EXCEED 90° F.

MAX LEAK RATE 1.5 10⁻⁶ ST/CL SEC. HELIUM GAS.

PAS SPEC. SPEC. AS SHD EXCEPT OMIT THE REQ. FOR
FLUORESCENT PENETRANT INSPECTION (PASS 2.4.3).
AS-B-300 CL 4043.

JUST TAKE UP CLEARANCE WITHIN EACH STACK OF
CLAMP.

3, 5 AND 7 TO FILL UP THE GAP BETWEEN THE BAND
BAND ASSY. THE SAME AMOUNT OF GAP SHALL
EACH BAND ASSY. EACH BAND ASSY A CONSIDERATION USING
POSSIBLE RATHER THAN SEVERAL THIN PARTS.

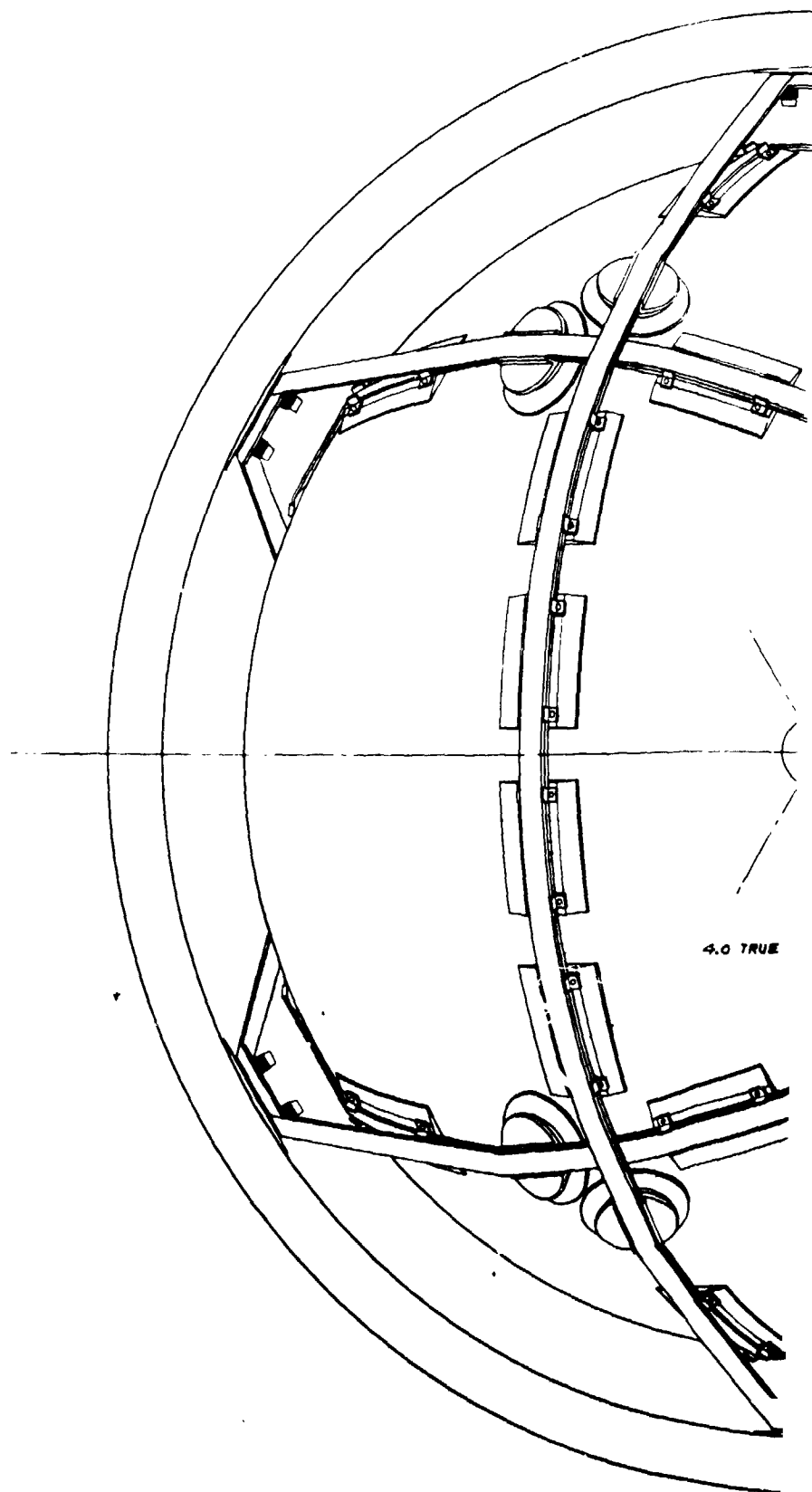
REVISIONS			
NO.	DATE	DESCRIPTION	BY
1	10-22-70	NEW CHANGE: RELOCATED (REDUCED) QTY OF 46099-1 ASSOCIATED WITH REDESIGNED -19. ADDED -21, -22 & TAT16 WHAT. (NOW) WAS 1216-12H56P (WAS) WAS 1216-12H56P. REVISED INSTL INSTRUCTIONS. REASONS: TO AGREE WITH DESIGN OF PV INSULATION PARTS TO BE INSTALLED ON LATER ASSY. TO CORRECT BOLT LENGTH TO UP-DATE INSTL INSTRUCTIONS. EFFECTIVE: 1ST UNIT AFTER. DISPM: FW. SCRAP UN-USEABLE UNNEEDED PARTS. CLASS 12B	
2	11-15-70	INCRP. CA # D03881 L/C 246	

AS REQD	AS REQD	AS REQD	WELD WIRE	66-7-366 AL WELD CL 4043	3A
	2		CLAMP	7M76WHHT	5C
	4		CLAMP	7M683HHT	9C
	142		SCREW-CAP	WAS1352C3H10	8B
	10		SCREW-CAP	WAS1352C3H8	5C
	12		BOLT	WAS1351-12H56P	8C
AS REQD			FLAT WASHER	AN960-1216	8C
	142		FLAT WASHER	AN960C10L1	8B
AS REQD			FLAT WASHER	AN960-10	8D
	152		SPRING LOCK WASHER	SIMILAR TO AN935-10	8N
	24		SCREW	MS3249-01	8D
AS REQD			SAFETY WIRE	MS2099SC40	8C
	1		GIRTH RING ASSY	660968-1	9D
	1		PRESS VESSEL ASSY	660961-1	5B
	12		PAD ASSY	560962-1	8D
	1	34	SHOE	460991-1	8A
	1		BAND ASSY	460985-5	9D
	1		BAND ASSY	460985-2	8C
	1		BAND ASSY	460985-1	8B
	12		CLAMP	360986-1	8D
	142		RETAINER	260973-1	8A
	1		SHOE ASSY		6C
	1		SHOE ASSY		6B
	1		BLOCK-CLAMP		5B
	36 MAX		SHIM		8A
	36 MAX		SHIM		8A
	12 MAX		SHIM		8D
	12 MAX		SHIM		8D
	6		PLATE		8C
			SHIM		8D
			SHIM		8D
			SHIM		8D
			ASSEMBLY		1

LIST OF MATERIALS OF PARTS LIST		Boech Aircraft Corporation SUPPORT INSTALLATION	
J 07899		660969	

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR,

FOLDOUT FRAME (



460985-3

AFTER COMPLETION OF ASSY
REMOVE BOLTS & WASHERS
FROM 560962-11
TYP 48 PLACES

MS 35265-69 2 REQD
AN960-10 AS REQD
352986-1
TYP 12 PLACES REMOVE
AFTER COMPLETION OF ASSY

460985-3 (REF)

SEE DETAIL 19A

AS REQD TYP 12 PLACES

560962-1 TYP 12 PLACES

5 TYP 48 PLACES
BEND END OF -11 AGAINST
END OF 560962-14 BEND
END OF -13 AGAINST END OF -11

VIEW 13-13
VIEW ROTATED
FOR CLARITY
SCALE: 1/2



SEE DETAIL 19A

SEE DETAIL 19A

NAS1351-12H56P 12 REQD
AN960-1216 AS REQD
SAFETY WIRE BOLT
PAIRS USING MS20995C40
PER MS33540

460985-3

NAS1352-3H8
WASHER SIMILAR TO AN935-10
TYP 8 PLACES

BOILER TUBE (REF)

VENT TUBE (REF)

10 MIN TYP 2 PLACES

FILL TUBE (REF)

10 MAX TYP 2 PLACES

10 MAX TYP 2 PLACES
TYP 2 PLACES

TA4CG85514T
TYP 4 PLACES

460985-1

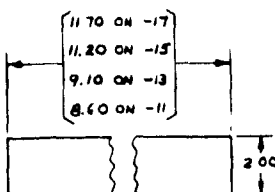
560962-1 (REF)
CENTER ON THE TSC
FLAT ON THE BAND A
TYP 12 PLACES

30°

30°

18 PLACES
20 TRUE
TYP 6 PLACES

4 TRUE TYP 72 PLACES
1.85 ± .02
TRUE TYP
72 PLACES
MIN
MIN
TYP 36 PLACES



DETAIL -11, -13, -15, -17
SCALE: 1/2

460985-1 (REF)

NAS1352C3H10
WASHER SIMILAR TO AN935-10
AN960C10L
TYP 142 PLACES

260973-1
TYP 142 PLACES

SEE DETAIL 19A
AS REQD TYP 36 PLACES

460991-1
TYP 36 PLACES

VIEW A-A
VIEW ROTATED
FOR CLARITY
SCALE: 1/2

5 TYP 144 PLACES
BEND END OF -15 AGAINST
END OF 460991-1 & BEND
END OF -17 AGAINST END OF -15

P VIEW

FOLDOUT FRAME 2

660969

PLACES
- AGAINST
142-1 & 3 END
AGAINST END OF -11

* 360962-1 (REF)
CENTER ON THE 750
FLAT ON THE BAND ASSY
TYP 12 PILES

460941-1 (REF)
 LOCATE END OF -5
 CR-17, AS REQD, AT
 BEND IN BAND ASSY
 (REF 500 DIM ON
 460985) TYP 12
 PLACES.

4 NBT
END
NO OF -15.

3 TYP 12 PLACES

TAP - 4
 - 1.25
 NAS 135 2346
 WASHES 1.42 TO AN935 10
 TYP PLACES

SECTION C-C: 68
SCALE: 1/2"
BAND ASSEMBLY ATTACH
NOT SHOWN FOR CLAR.

FOLDOUT FRAME 3

FOLDOUT FRAME

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

AS REQD	WELD WIRE	MIL-B-508 CRCS ER 347 WELD CL 34	34
2	CAP ASSY	AN929-20CRCS	8A
2		AN929-16CRCS	8C
2		AN929-8CRCS	8C
1	CAP ASSY	AN929-4CRCS	8B
2	TUBE END REDUCER	20-16T8TX-SS	8A
2	TUBE END REDUCER	8-4T8TX-SS	8B
2	MALE CONNECTOR	4-8F8TX-SS	8B
2	FEMALE CONNECTOR	4-4G8TX-SS	9A
2	PRESSURE GAGE	137-5C-KMB 4 1/2" SIZE	8C
1	NEEDLE VALVE	1335G4-Y	8B
2	BALL SHUTOFF VALVE	10D101-1" TUBE SIZE	7D
1	PANEL MOUNTING KIT	2359(1/2)	6C
1	BALL SHUTOFF VALVE	1/2-4033TF	6C
16	NUT PLAIN, HEX STEEL, 1/10-22		8C
16	WASHER, FLAT	AN960-2616L	9A
16		AN960-2116L	8C
16		AN960-1216L	8B
8		AN960-716L	8B
16		AN960-416L	8A
39	WASHER, FLAT	AN960-10L	8B
6	WASHER-LOCK, SPRING	AN935-10	8C
2	UNION-FLARED TUBE BULKHEAD UNION- 3/4" FITTING	AN924-20CRCS	8A
2		AN924-16CRCS	8C
2		AN924-8CRCS	8B
1	NUT-FLARED TUBE BULKHEAD UNION- 3/4" FITTING	AN924-4CRCS	8B
2	UNION-FLARED TUBE BULKHEAD UNION- 3/4" FITTING	AN932-20CRCS	8A
2		AN932-16CRCS	8C
2		AN932-8CRCS	8B
1	UNION-FLARED TUBE BULKHEAD UNION- 3/4" FITTING	AN932-4CRCS	8B
1	TEE-FLARED TUBE	AN924-8CRCS	10C
1	TEE-FLARED TUBE	AN924-4CRCS	8B
2	NUT, COUPLING	AN918-20CRCS	8A
8		AN918-16CRCS	8A
7		AN918-8CRCS	8B
8	NUT, COUPLING	AN918-4CRCS	8B

25	SCREW	AN525-10-12	5A
8	SCREW	AN525-10-10	7D
8	BOLT	AN4-32	5A
8	SLEEVE, FLARED TUBE FITTING	MS20819-16CRCS	8A
5		MS20819-8CRCS	8C
8	SLEEVE, FLARED TUBE FITTING	MS20819-4CRCS	8B
33	NUT SELF LOCKING	MS20365-10-2	5A
8	NUT SELF LOCKING	MS20365-418	5A
15 AS REQD	WELD WIRE	DD-A36AL WELD CL 4043 WIRE	8B
1	TUBE	43	9D
1	TUBE	44	6C
1	TUBE	39	9C
1	TUBE	37	9C
1	TUBE	35	8B
1	TUBE	33	7D
1	TUBE	31	9B
1	TUBE	29	8B
1	TUBE	27	9D
3	TUBE	25	6C
4	BRACKET-SUPPORT	28	7A
1	PANEL-TOP	21	6A
1	PANEL-SIDE	19	5C
1	PANEL-SIDE	17	9A
1	NEVER USED	15	
2	BRACE-CROSS LOWER	13	9A
2	BRACE-CROSS- UPPER	11	9A
1	BRACE- LENGTHWISE	9	6C
1	BRACE- LENGTHWISE	7	8C
2	LEG	6	5B
2	LEG	5	5A
1	BOX ASSY	3	5A
1	ASSY	1	

LIST OF MATERIALS ON EACH SUB

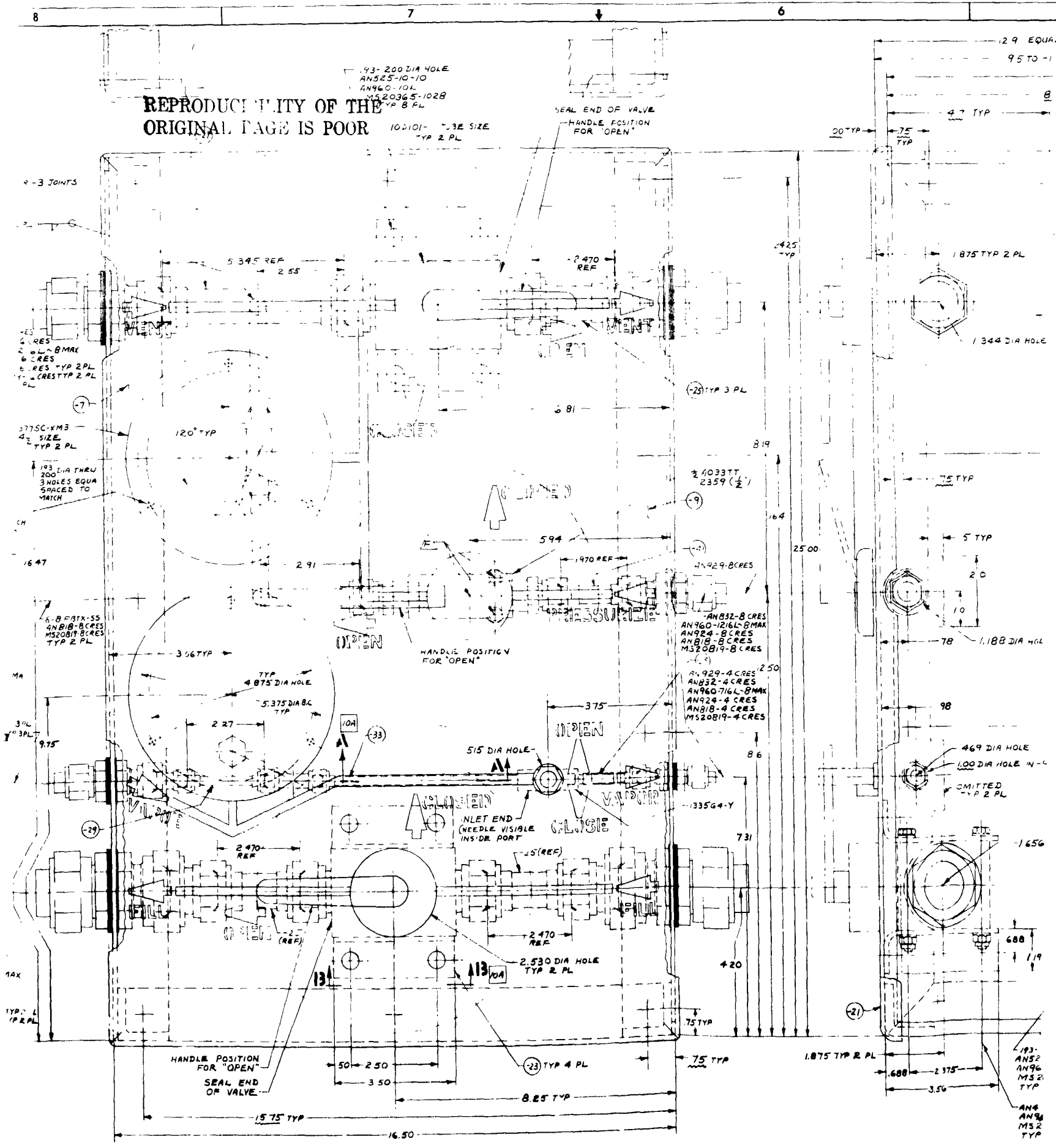
660995

Search Aircraft Corporation
MODULE CONTROL, EXTERNAL
J 07399 660995

AMP

BOLDBOUT FRAME 3

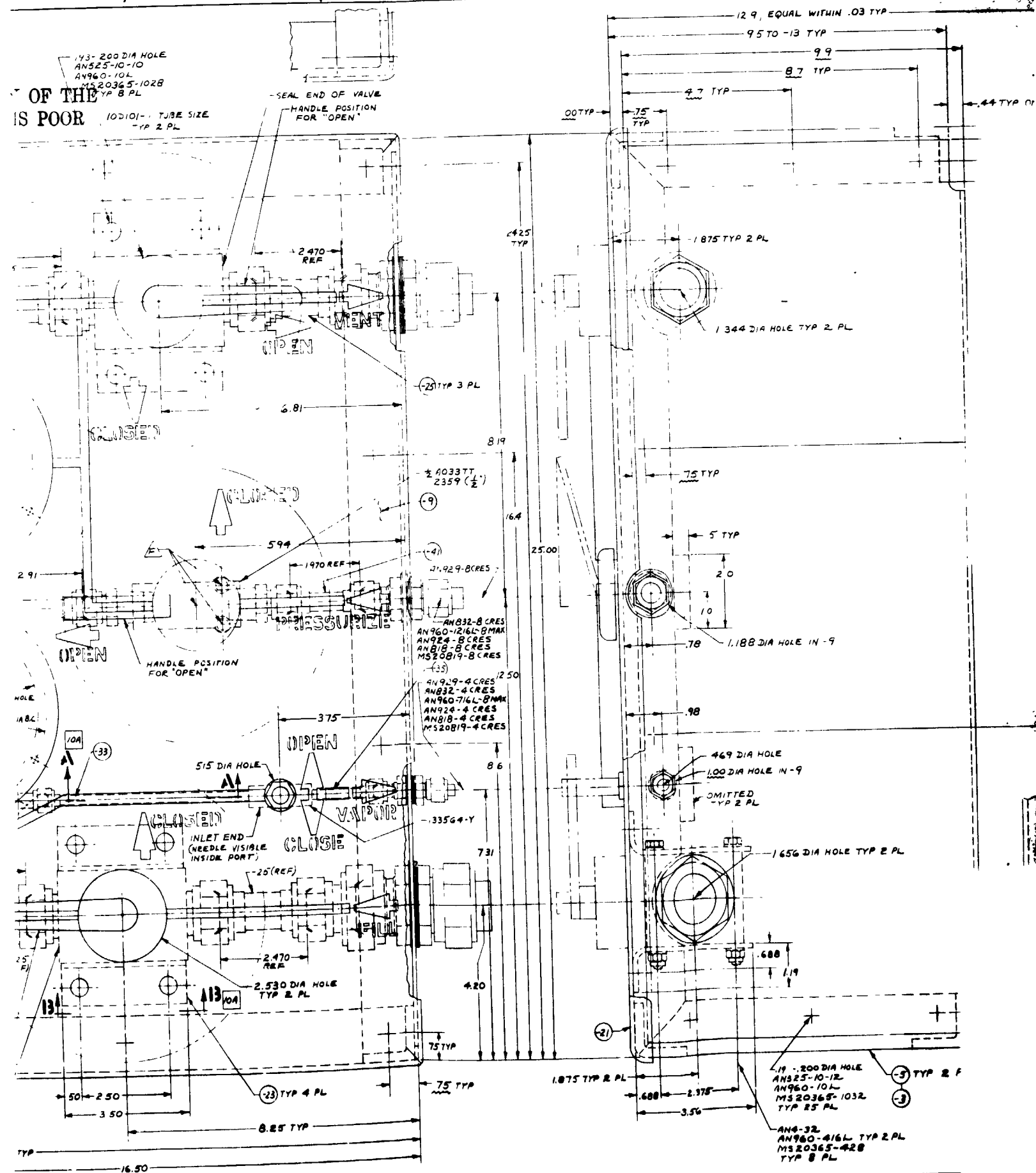
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ER 15961
June 15, 1973

A P P E N D I X B

INSTRUMENT LOCATION

Temperature Measurement Channel Identification - Table 3



ER 15916
June 15, 1973

TABLE 3
TEMPERATURE SENSOR IDENTIFICATION AND LOCATION

<u>TS</u> <u>No.</u>	<u>BP-15438</u> <u>Ident.</u>	<u>Type</u> <u>Sensor</u>	<u>Serial</u> <u>No.</u>	<u>Location</u>
1	a	cc	N/A	Chamber air above tank
2	b	cc	N/A	Chamber air opposite #1
3	c	cc	N/A	Chamber air above tank
4	d	cc	N/A	Chamber air opposite #3
5	I	cc	N/A	VCS outlet pipe
6	J	cc	N/A	Fill line outlet pipe
7	K	cc	N/A	Vent line outlet pipe
8	L	cc	N/A	Outer shell North Pole
9	M	cc	N/A	Outer shell South Pole
10	N	cc	N/A	Girth ring electrical connector
11	O	cc	N/A	Girth ring electrical connector
12	P	cc	N/A	Outer shell between girth and North Pole
13	Q	cc	N/A	Outer shell 180° opposite #12
14	R	cc	N/A	Outer shell between girth and South Pole
15	S	cc	N/A	Outer shell 180° opposite #14
23	C	Pt	271	In vacuum space on VCS tube on boiler outlet
24	B	Pt	270	In vacuum space on fill tube 1/2 inch outside boiler
25	A	Pt	269	In vacuum space on P.V. at North Pole
26	D	Pt	290	In vacuum space on VCS approx. midway
27	G	Pt	261	In vacuum space on support band over insulation pad
28	F	Pt	262	In vacuum space on support band between pads - North Pole
29	E	Pt	273	In vacuum space on VCS tube band nearest girth outlet
30	H	Pt	274	In vacuum space on VCS tube at VCS outlet



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June 15, 1973

APPENDIX C

DESIGN DATA

Support Member Load - Table 4



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Jun 15, 1973

TABLE 4 MEMBER LOADS

Cond.	N _x = 3.0				N _x = 7.0				N _x = 3.0 + H _z = 3.5			
Geom.	Print	Deflected		Print	Deflec	ed		Print	Deflected			
F. Coef.	0	0	0.1	0.2	0	0.1	0.2	0	0	0.1	0.2	
ITEM												
I ₉	34667	32613	32613	26892	26815		48113	46020				
T ₁	35220	33226	32342	31493	27321	272,7	26412	25611	48880	45550	44300	
P ₁	10,93	8837	8659	8487	8296	8353	8183	8020	14841	13013	12750 12500	
I ₄	35220	33226	27725	22989	27321	27247	26412	25611	48880	46850	40930 35800	
T ₆	35219	33234	26629	21202	0	0	0	0	Same as N _x = 3.0			
P ₅	14295	13202	10797	8777	8296	8353	8183	8020	18443	17380	14890 12790	
I ₇	35219	33234	23647	18239	0	0	0	0				
T ₇ ¹	35018	33044	23514	18135	0	0	0	0	Same as N _x = 3.0			
P ₇	3761	3519	2525	1948	0	0	0	0				
Y ₂	752	710	691	673	583.5	582.2	564.3	547.2	1044	1001	973 947	
Y ₄	752	710	593	434	583.5	582.2	564.3	547.2	1044	1001	875 708	
Y ₆	752	710	569	453	0	0	0	0				
Y ₇	752	710	506	390	0	0	0	0	Same as N _x = 3.0			
f ₉	55915	52600	52600	52600	43374	43250			77600	74230		
I ₁	31446	29658	28870	28114	24394	24328	23582	22864	43640	41830	40670 39550	
f ₂	31446	29658	24086	18120	24394	24328	23582	22864	43640	41830	36550 31960	
f ₆	70438	66406	41812	37458	0	0	0	0				
f ₇	70438	66406	45912	32184	0	0	0	0	Same as N _x = 3.0			
f ₇ ¹	77036	66026	45650	32000	0	0	0	0				



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APPENDIX D

TEST RESULTS

Liquid Nitrogen Heat Leak Test Record - 1971	Figure 18
Liquid Nitrogen Thermal Test Record - 1972	Figure 19 & Figure 20
Liquid Hydrogen Thermal Test Record - 1972	Figure 21
Liquid Helium Thermal Test Record - 1972/1973	Figure 22 & Figure 23 & Figure 24

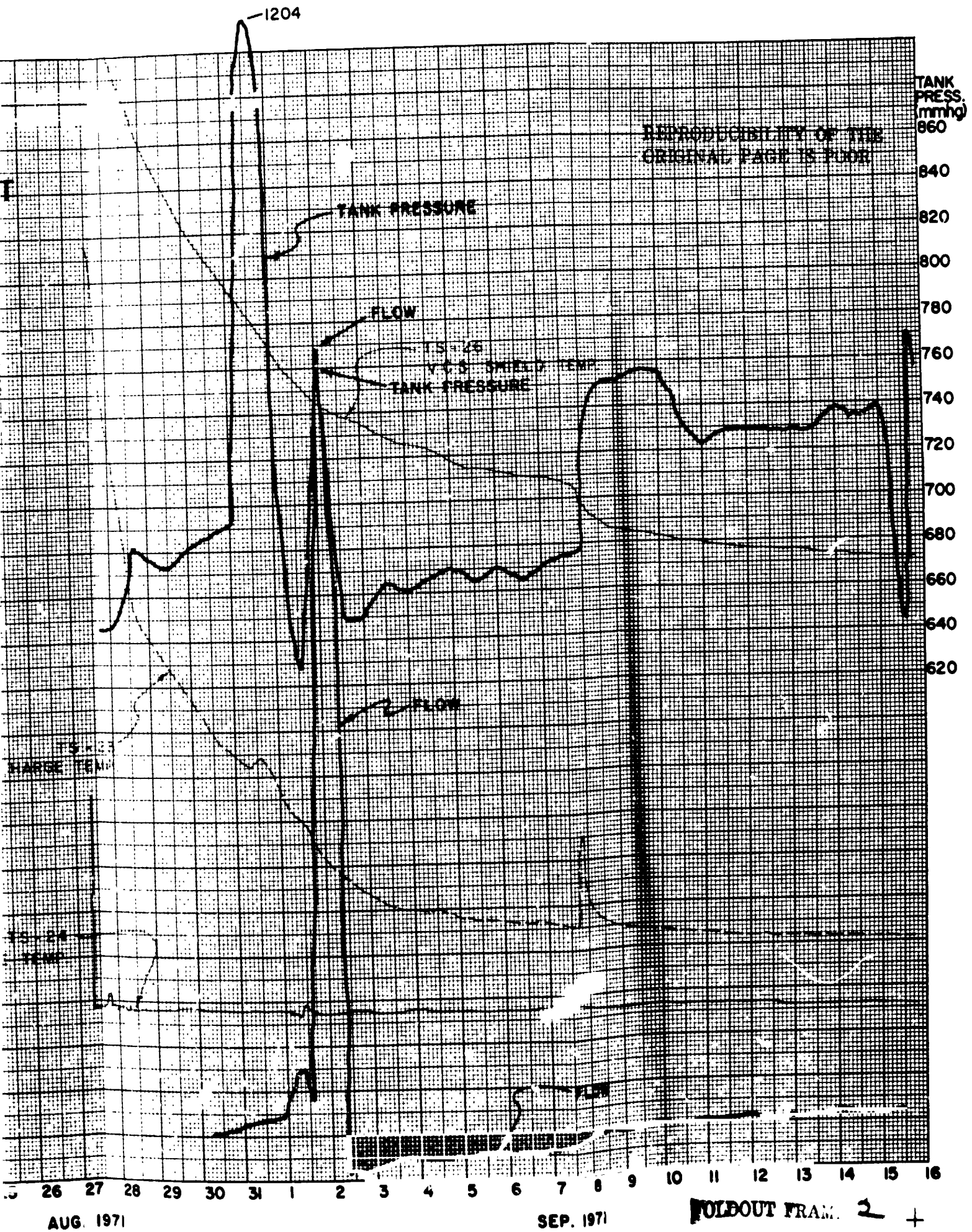
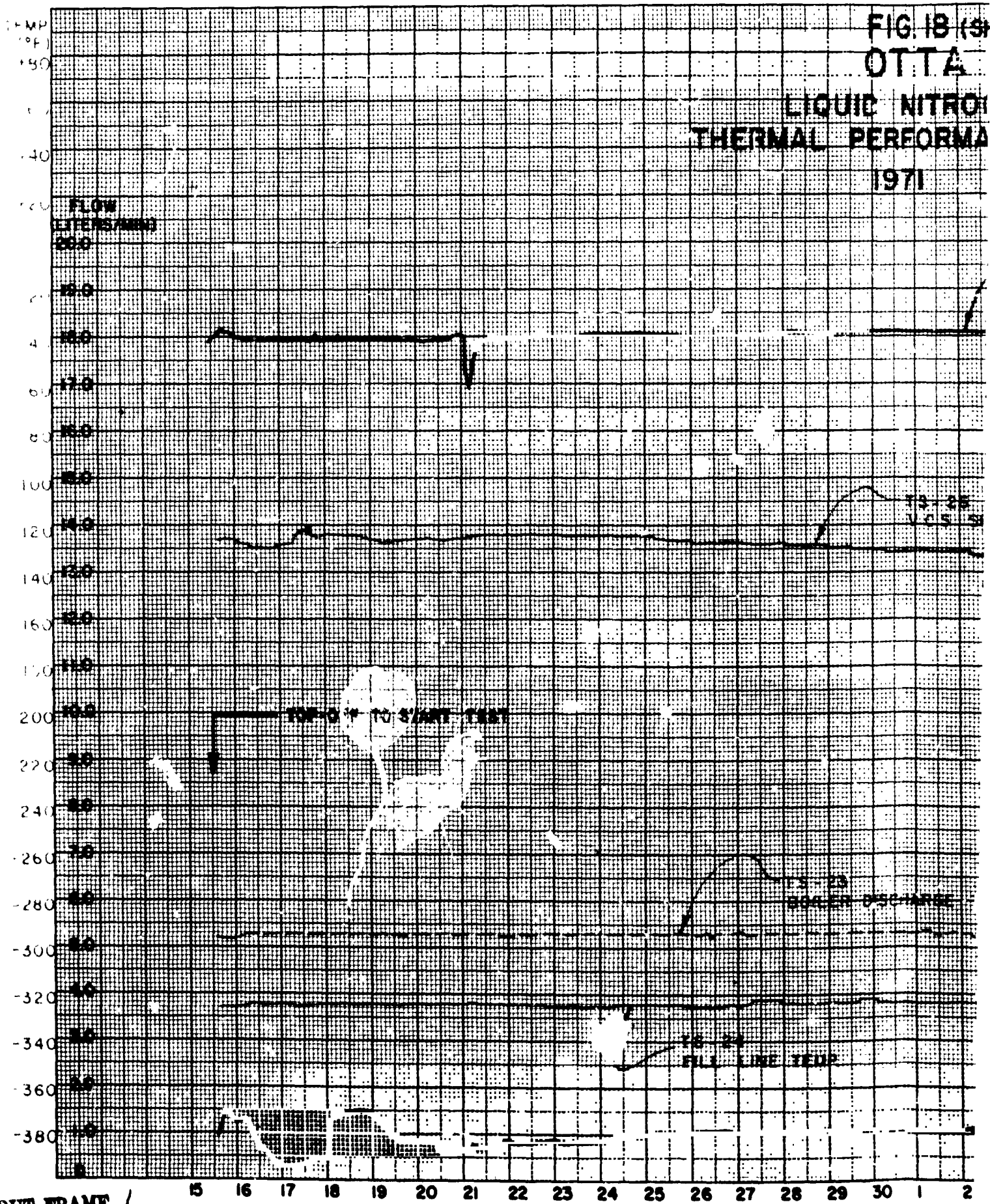


FIG. 18 (9)

OTTA

LIQUID NITRO
THERMAL PERFORMA

1971



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SEP. 1971

FIG. 18 (SHEET 2)

OTTA

JHD NITROGEN
PERFORMANCE TEST

1971

TANK
PRESS.
(mmhg)

840

820

800

780

760

740

720

700

TANK PRESSURE

TEMP

ER DISR - TEMP

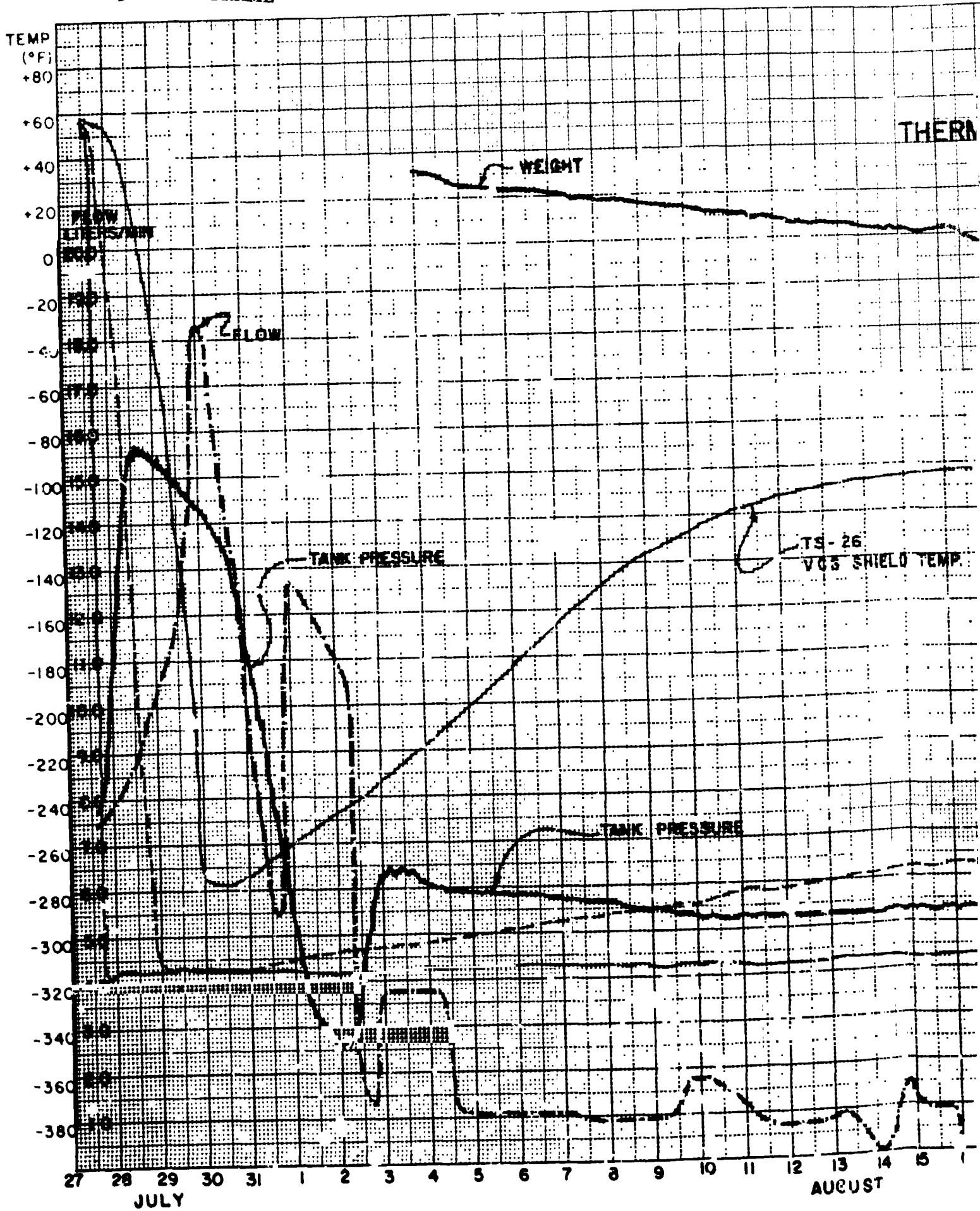
VCS
FLOW

29 30 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

OCT. 1971

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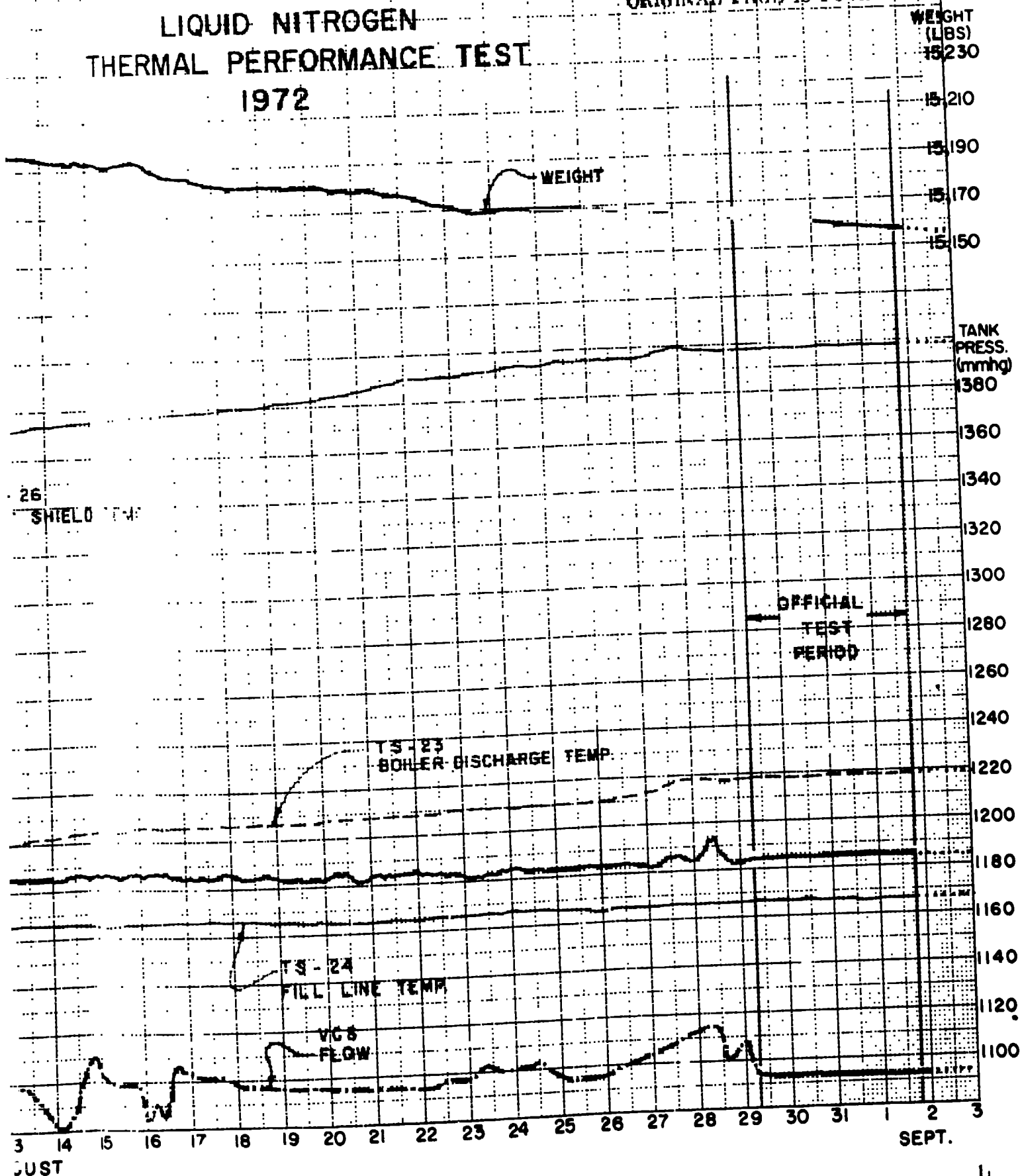
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FIG.19
OTTA
LIQUID NITROGEN
THERMAL PERFORMANCE TEST
1972

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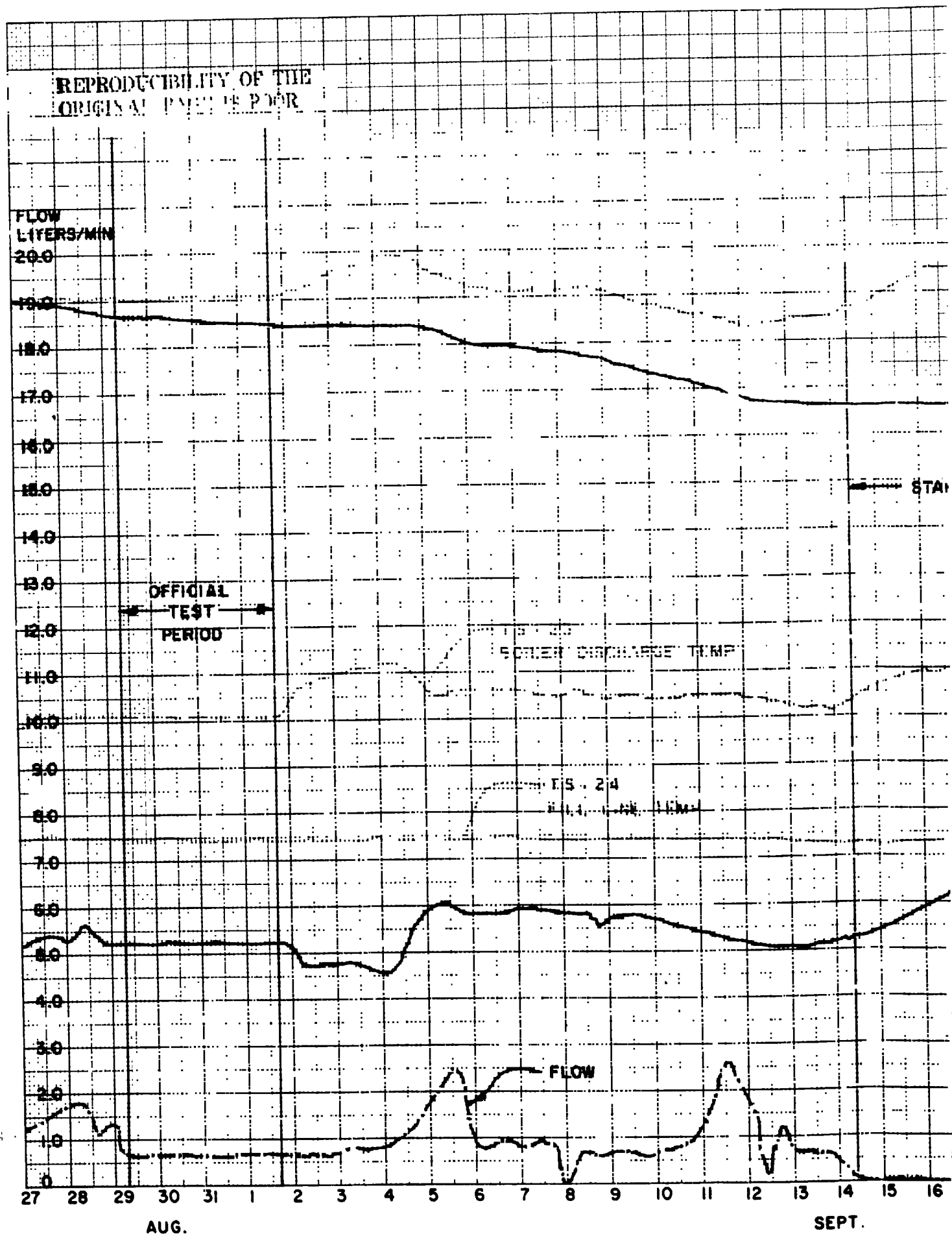
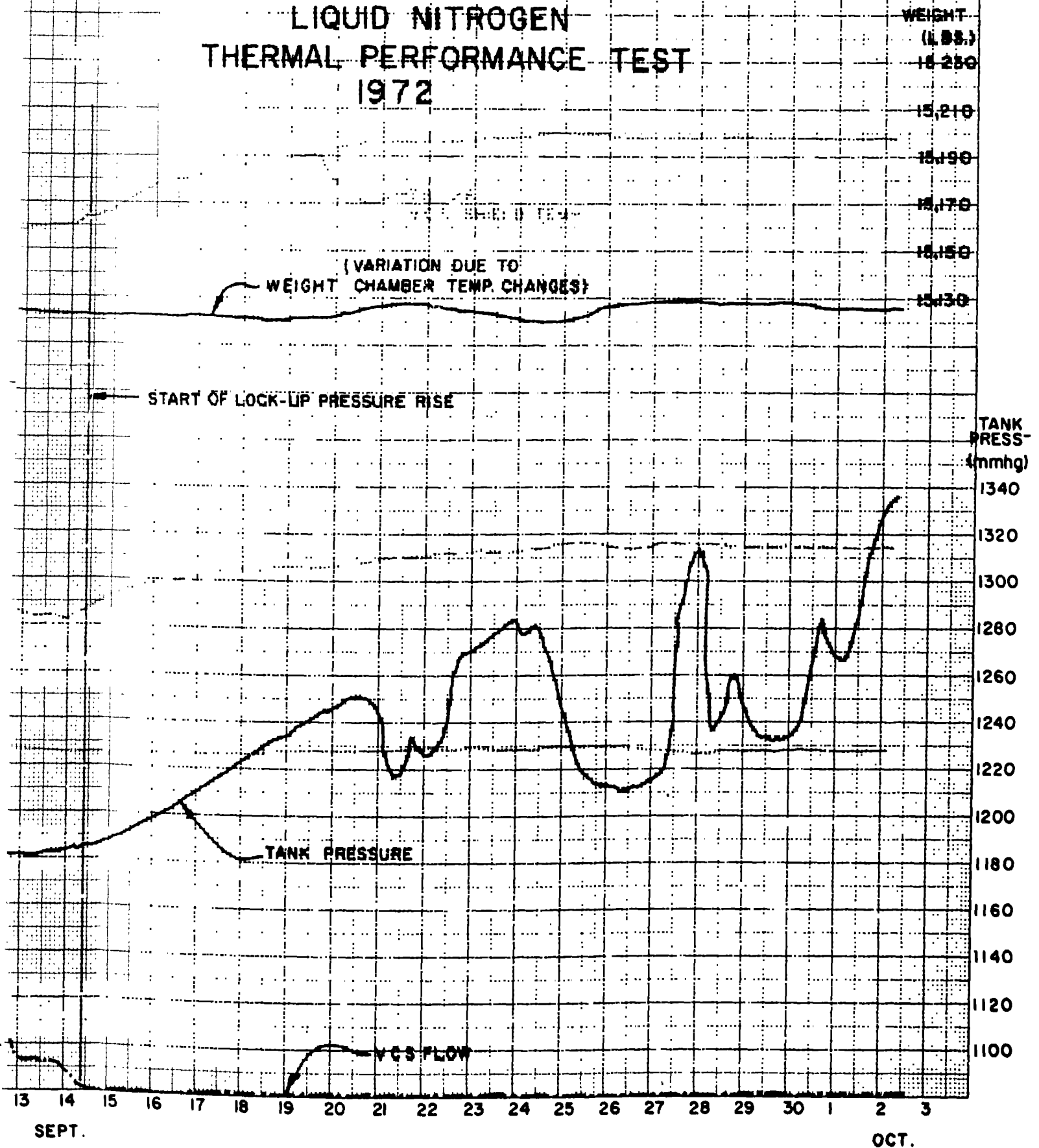
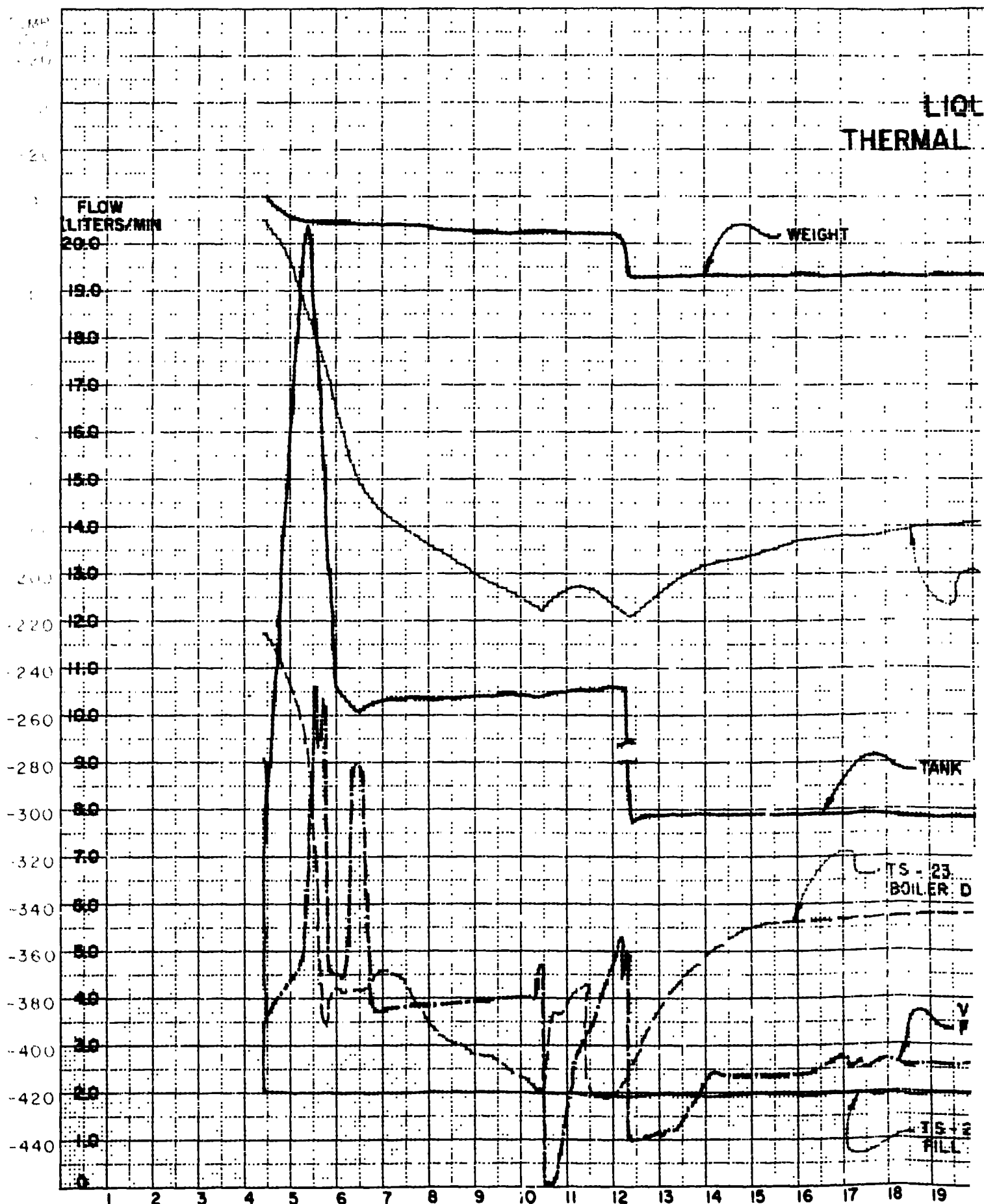


FIG. 20
OTTA
LIQUID NITROGEN
THERMAL PERFORMANCE TEST
1972



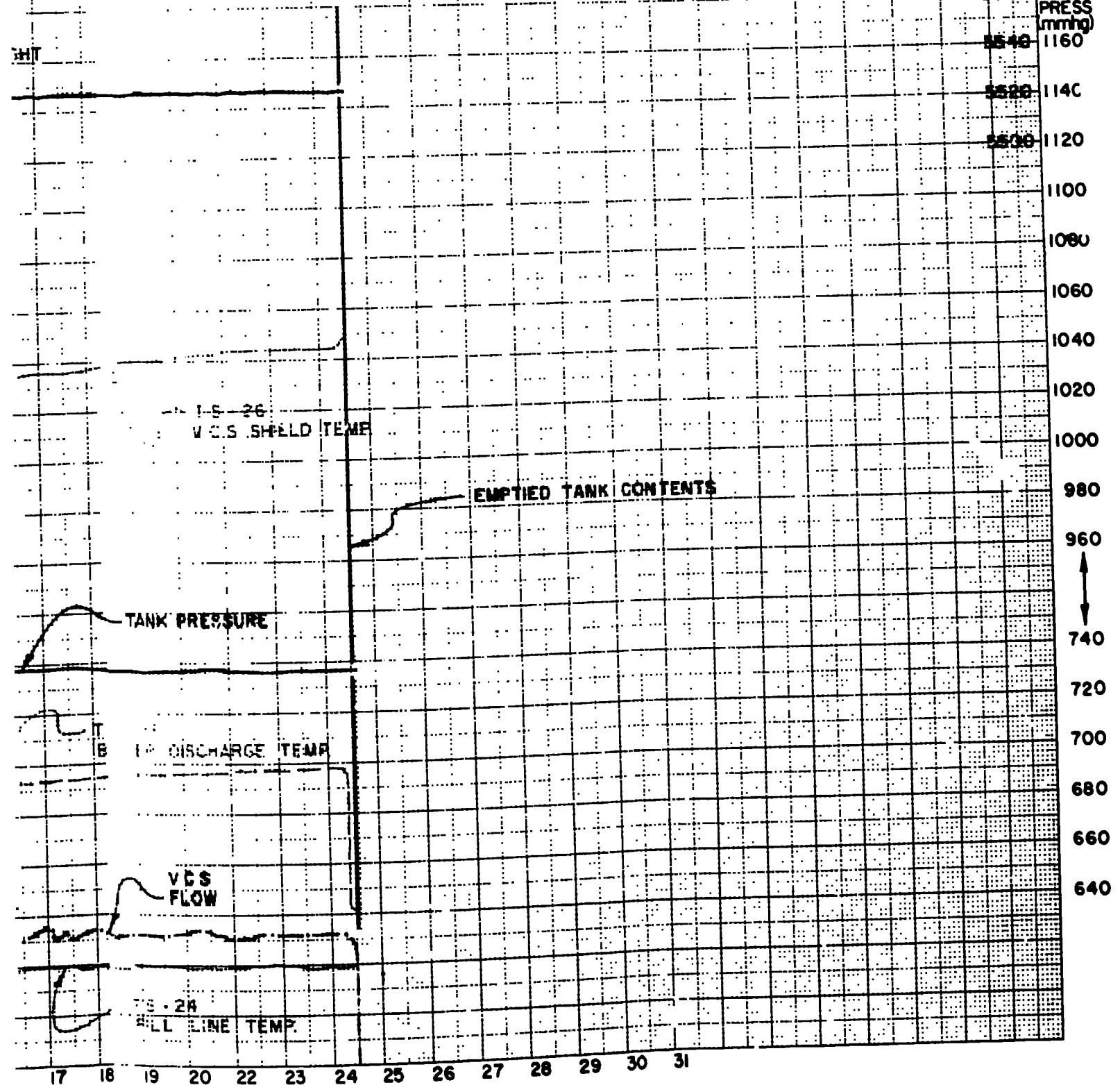
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OCTOBER 1972

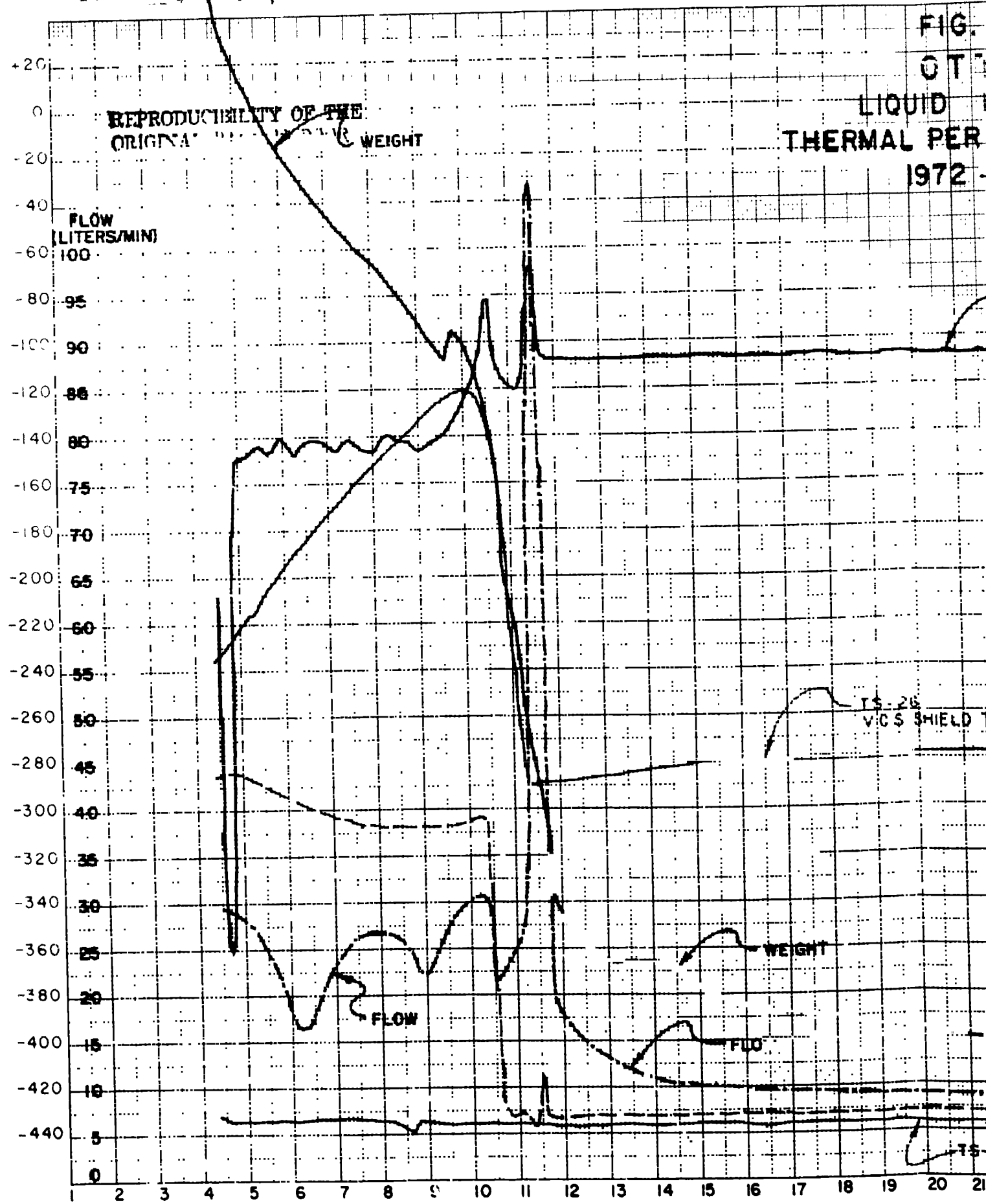
FIG. 21
OTTA

LIQUID HYDROGEN
THERMAL PERFORMANCE TEST
1972



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FIG. 1
OT
LIQUID
THERMAL PER
1972



NOV. 1972

FIG. 22

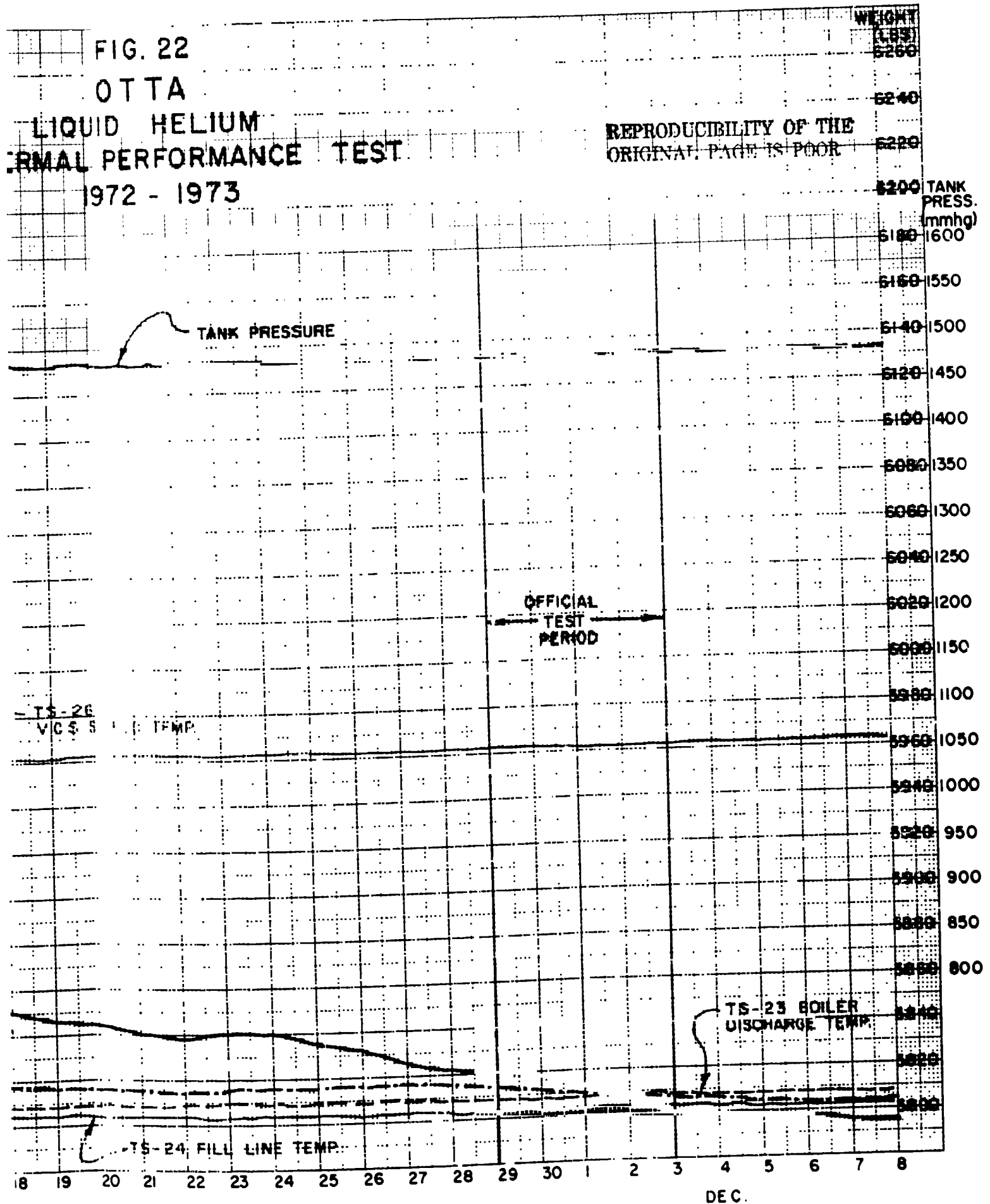
OTTA

LIQUID HELIUM

RMAL PERFORMANCE TEST

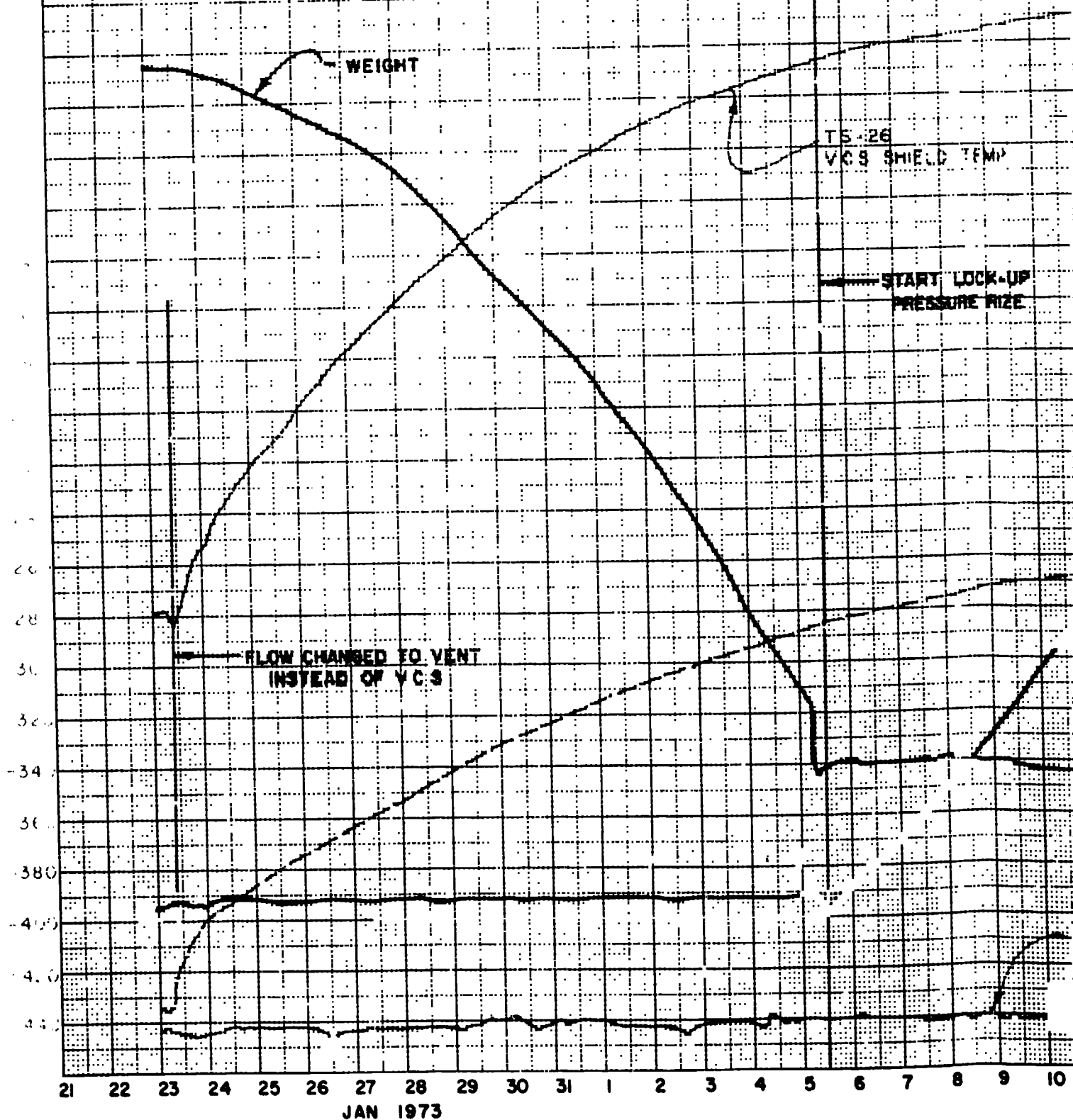
1972 - 1973

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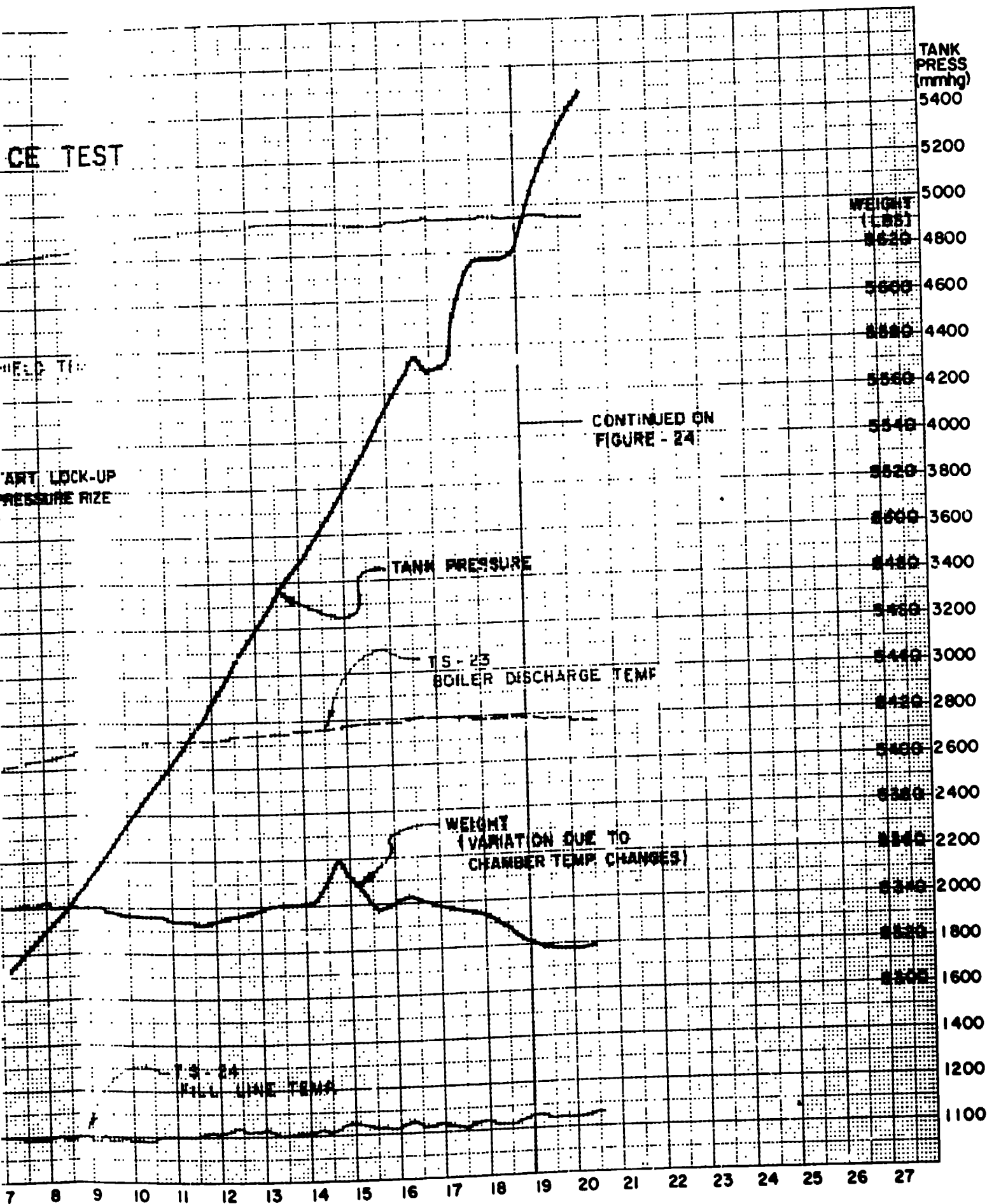
FIG. 23
OTTA
LIQUID HELIUM
THERMAL PERFORMANCE TEST
1972-1973



CE TEST

WELD T

ART LOCK-UP
PRESSURE RISE



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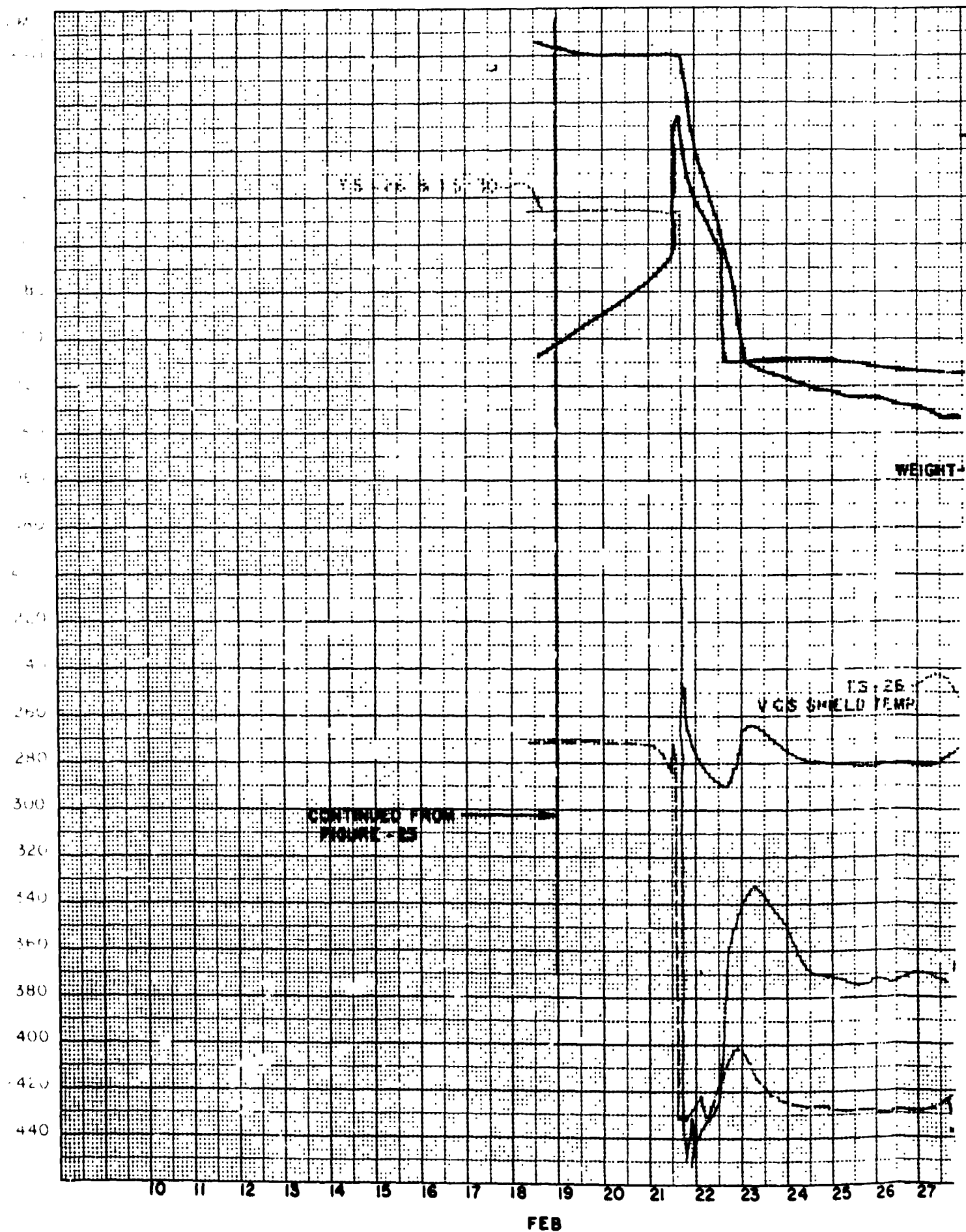


FIG. 24 OTTA LIQUID HELIUM THERMAL PERFORMANCE TEST 1973

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